# ARCHAEOLOGICAL OTOLITHS AS ENVIRONMENTAL RECORDERS: HIGH RESOLUTION SAMPLING OF PACIFIC COD (GADUS MACROCEPHALUS) OTOLITHS FROM KISKA ISLAND, ALASKA.

by

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## ABSTRACT

Archaeological fish otoliths have the potential to serve as proxies for both season of site occupation and palaeoclimate conditions. By sampling along the distinctive sub-annual seasonal bands of the otolith and completing a stable isotope ($\delta^{18}O$, $\delta^{13}C$) analysis, variations within the fish's environment can be identified. Through the analysis of cod otoliths from two archaeological sites on Kiska Island, Gertrude Cove (KIS-010) and Witchcraft Point (KIS-005), this research evaluates a micromilling methodological approach to extracting climatic data from archaeological cod otoliths. In addition, $\delta^{18}O_{otolith}$ data and radiocarbon dates frame a discussion of Pacific cod harvesting, site occupation, and changing climatic conditions on Kiska Island. To aid in the interpretation of the archaeological Pacific cod results, archaeological and modern Atlantic cod otoliths were also analyzed as a component of this study to develop. The Atlantic cod otoliths provided the methodological and interpretative framework for the study, and also served to assess the efficacy of this sampling strategy for archaeological materials and to add time-depth to existing datasets.

The $\delta^{18}O_{otolith}$ values successfully illustrate relative variation in ambient water temperature. The Pacific cod $\delta^{18}O$ values demonstrate a weak seasonal signal identifiable up to year 3, followed by relatively stable values until year 6/7 when values continuously increase. Based on the $\delta^{18}O$ values, the Pacific cod were exposed to the coldest water temperatures immediately prior to capture. The lack of a clear cycle of seasonal variation and the continued increase in values towards the otolith edge obscures the season of

capture, and indicates that other behavioural, environmental, or methodological factors influenced the otolith $\delta^{18}O$ values.

It is suggested that Pacific cod would have been harvested throughout the year, and the presence of cod remains in Aleutian archaeological sites cannot be used as a reliable indicator of summer occupation. In addition, when the $\delta^{18}O$ otolith values are integrated with radiocarbon dates and known climatic regimes, it is demonstrated that climatic conditions play an integral role in the pattern of occupation at Gertrude Cove. Initial site occupation coincides with the end of a neoglacial cooling period, and the most recent and continuous occupation coincides with the end of a localized warming period and the onset of the Little Ice Age (LIA).

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## Chapter 1: Introduction

The geographically isolated islands of the Aleutian archipelago provide an interesting context to examine the complex relationship between populations living in a subarctic maritime environment and their available marine resources. The island chain, extending approximately 1800 kilometres between the North American and Asian continents, is home to a rich and diverse marine ecosystem and has undergone extensive environmental changes since the first inhabitants colonized the archipelago approximately 9000 years ago (Corbett et al. 2008:44; West et al. 2010:482). Developing a clearer understanding of these environmental changes over time and space continues to be a main component of both biological and archaeological research in the region (e.g., Causey et al. 2005; West et al. 2007; Williams et al. 2003). Through high resolution stable isotope analysis, temporally specific marine climatic data can be obtained from carbonate structures, such as fish otoliths, to investigate climatic variation over time and seasonal patterns within the archaeological record.

Estimating patterns of seasonal resource use is an integral component of archaeological studies (Monks 1981:178). The study of incremental structures, such as otoliths, as a means of inferring seasonality is one of several methods used in the broader discussion of seasonality in the archaeological record (Monks 1981:193). Incremental structures also play an integral role in interpreting and reconstructing palaeoenvironmental conditions and the relationship between these conditions and human behaviour, especially as high-resolution sampling methods provide increasingly tighter temporal and spatial control (Twaddle et al. 2015:2).

Otoliths are paired inner ear structures in fish composed primarily of calcium carbonate; they develop in sequential layers in chemical equilibrium with the surrounding water, and can act as environmental recorders (Campana 1999; Elsdon et al. 2008:298; Hanson et al. 2010:2491). The outer margin of the otolith is deposited closest to the time of capture, and acts as an archaeological indicator of the season of site occupation. Archaeological fish otoliths serve as proxies for both the season of site occupation and palaeoclimate conditions. By micro-sampling along the distinctive sub annual bands of the otolith and completing a stable oxygen isotope ($\delta^{18}O$, $\delta^{13}C$) analysis, variations within the fish's environment can be identified. Through the analysis of otoliths and the inclusion of radiocarbon dates from Kiska Island, this project discusses evidence for season of Pacific cod (*Gadus macrocephalus*) harvesting and changing climatic conditions over time, as inferred from cod ambient water conditions.

Additionally, this project serves as a methodological investigation into the efficacy of applying these geochemical and fisheries management techniques to archaeological samples, as archaeological otolith data has a valuable role in both future archaeological and fisheries biology research. As Betts et al. (2011:188) points out, in the "Archaeology of North Pacific Fisheries", the archaeological evidence for over 5000 years of interaction between humans and cod in the northern hemisphere highlights that the application of half a century's worth of fisheries data is insufficient to inform effective management strategies.

The main objectives of this research are to 1) evaluate this methodological approach for the extraction of climatic data from archaeological cod otoliths 2) identify season of capture and apply this to a discussion of Pacific cod harvesting in the Aleutians,

and 3) identify relative changing ambient water conditions. This research demonstrates that the methodological approach effectively provides climatic data at a tight temporal resolution. The development of modern, historic, and prehistoric Pacific cod baselines and population indicators are integral to the continued application of this methodological approach in archaeological contexts.

Season of capture was not clearly identifiable through the microstructural and isotope analysis due to the lack of clear cyclical seasonal variation within the $\delta^{18}O$ values. Overall, the Pacific cod $\delta^{18}O_{otolith}$ values in this research demonstrate a weak pattern of inter-seasonal variation and minimal overall variation in ambient water conditions. The general pattern in $\delta^{18}O$ values identified here is an initial depleted hatch value, followed by a spike at the first winter, with a weak seasonal signal identifiable up to year 3, followed by relatively stable values until year 6/7 when values continuously increase. The $\delta^{18}O$ values demonstrate that the fish were exposed to the coldest water temperatures immediately prior to capture. This research indicates that the variation in cod $\delta^{18}O_{otolith}$ values identified here is heavily influenced by habitat and behaviour, which obscures patterns of cyclical seasonal variation.

Archaeologically, Pacific cod harvesting is considered to primarily occur during spring and summer when cod reputably move inshore (e.g. Knecht and Davis 2008; Lefèvre 1997; West et al. 2012). Through the discussion of season of capture and cod harvesting, it is suggested that the presence of cod remains in western Aleutian archaeological sites is not indicator of spring and summer occupation, but that continued analysis of Pacific cod distributions in western Aleutian archaeological sites can contribute to the discussion of the seasonal use of resources.

Relative changes in ambient water conditions, inferred from cod $\delta^{18}O_{otolith}$ indicate minimal variation throughout the occupation of Gertrude Cove. The integration of radiocarbon dates and known climatic regimes demonstrate that climatic conditions were integral in the occupation of Gertrude Cove. Initial site occupation coincides with the end of a neoglacial cooling period at approximately 2500 BP, with the most recent and continuous occupation at Gertrude Cove coinciding with the end of a localized warming period and the onset of the Little Ice Age (LIA) around 600 BP.

Atlantic cod otoliths were also analyzed as a component of this study. This analysis was completed due to the availability of Atlantic cod otoliths and the existing familiarity with Atlantic cod at the facilities used for otolith analysis training. In addition, these otoliths provided a necessary foundation for the development of the methodological and interpretative framework for this research.

This thesis is organized into seven chapters, including the introduction (Chapter one) and conclusion (Chapter seven). Chapters two and three are context chapters, and address the archaeology and history of the western Aleutians and the role of otoliths as environmental recorders, respectively. Next, the methods are outlined (Chapter four), followed by the analytical results (Chapter five). The discussion (Chapter six) is presented by first integrating the isotope results with existing datasets and literature to discuss Pacific cod otolith $\delta^{18}O$, $\delta^{13}C$, and inferred ambient water conditions. The radiocarbon dates acquired from Gertrude Cove are then incorporated to discuss site chronology and Pacific cod harvesting. Finally, the palaeoclimate record is addressed, with radiocarbon dates and otolith data used to further identify the climatic regimes represented by the otoliths and spanning the duration of site occupation.

## Chapter 2: Western Aleutian and Kiska Island Context

### 2.1 The Western Aleutians: Environment and Setting

The Aleutian archipelago consists of over 200 islands and stretches approximately 1800 km between the North American and Asian continents (Corbett et al. 2008:44; West et al. 2007:47) (Figures 2.1and 2.2). The region is divided into five island clusters, which are separated by wide ocean passes (West et al. 2007:47). The climate is described as subarctic maritime with cool temperatures, dense fog, frequent rains, and violent winds (greater than 320 km per hour), but with minor overall fluctuations in seasonal temperatures (Corbett et al. 2008:44; Desautels et al. 1971:12; West et al. 2007:47; West 2012:1).


**Figure 2.1: Location of Study Area: Kiska Island, western Aleutians, Alaska.**

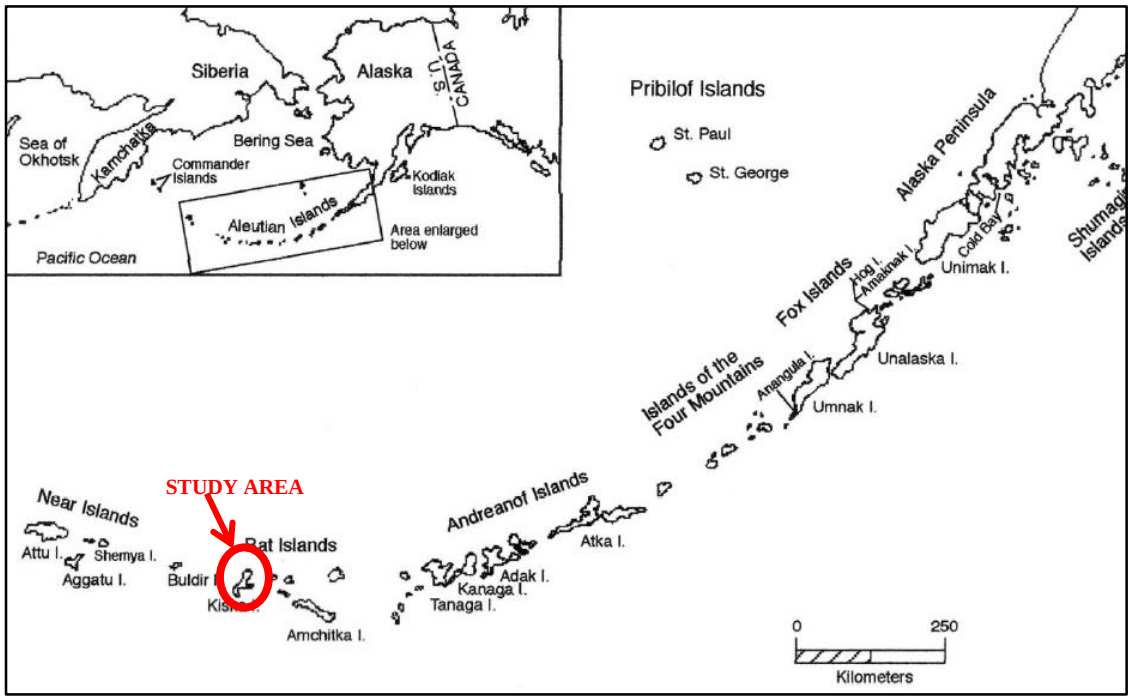



**Figure 2.2: Location of Kiska Island within the Aleutian Island chain (modified from West et al. 2007:48)**

The archipelago is a biotic bridge between the North American and Asian continents, and sustains rich ecosystems including ocean fisheries, sea mammal and seabird populations, kelp forests, complex near shore systems, intertidal zones, and spawning streams (Corbett et al. 2010:1; West et al. 2007:47; West et al. 2010:481). Warm, nutrient rich, west flowing Pacific currents and cold, oxygen rich, east flowing Bering Sea currents mix at the ocean passes creating high biological productivity surpassing that of either ocean (Corbett et al. 1997a:461; Corbett et al. 2008:44; Favorite 1965). The island chain is devoid of native terrestrial mammals west of Umnak Island, in the Fox Island group of the eastern Aleutians (Williams et al. 2003:176). As the northern section of the Ring of Fire volcanic zone, the archipelago is also ecologically characterized by massive tectonic activity and volcanic eruptions (Black 1981:315; West 2012:2).

This rich and extreme environment was pivotal for the human groups and their adaptation and survival as they colonized the archipelago (West et al. 2007:47). Over time, environmental and climatic conditions fluctuated impacting the human populations and the natural resources; modern climatic data suggests that this variation occurs most predominantly at a localized level (Rodionov and Overland 2005; Veltre 2012:37; West et al. 2007:51). Recent analyses indicate that the movement of people into the Aleutians is strongly correlated with climatic conditions, with colder sea temperatures and higher levels of biological productivity acting as stimuli for migration (Savinetsky et al. 2012; West et al. 2007). Hunting and fishing substantially contributed to ecological changes over time, which intensified with the introduction of industrial scale resource acquisition. Recent studies are only beginning to explore the complexity of the reciprocal relationship between human activities on the island chain and their resources throughout prehistory (e.g., Corbett et al. 2008; Knecht and Davis 2008; Krylovich 2011; Misarti et al. 2009; Moss 2011; Erlandson and Rick 2008).

Wider palaeoenvironmental trends have been given greater focus in the Aleutians than patterns of seasonal procurement, and variations in seasonal occupation and resource use requires further research (Funk 2011:47; e.g., Causey et al. 2005). Understanding and investigating seasonal patterns is integral to interpreting the archaeological record. As Twaddle et al. (2015:3) point outs, the exchange between cultural mechanisms and environmental conditions fundamentally influences human behaviour. Seasonal availability and preference play a role in patterns of seasonal resource acquisition, and the integration of these activities within the wider cultural context is also a main component of seasonal patterns of activities (Monks 1981:178). In the western Aleutians there is a limited

understanding of seasonal resource patterns, and at the nearby island of Buldir for example, site seasonality has been difficult to interpret (e.g. Lefèvre et al. 1997). The authors identify a summer and spring presence based on bird bones, but also suggest a year round presence based on marine mammal and the possibility of year round food storage (Lefèvre et al. 1997:125). Similarly for sites on Rat Island, Funk (2011:40) discusses variation over time in procurement patterns, but points out that variation in subsistence patterns over time influences interpretations of what appear as seasonal patterns in the archaeological record, and more research is required.

### 2.2 Kiska Island

Kiska is the westernmost island in the Rat Island group of the western Aleutians[1]. The Rat Island group consists of six islands including Kiska, Little Kiska and Amchitka (Veltre 2012:36). Buldir Island, 100 km west of Kiska, is the nearest island and has been a focal point for archaeological investigations (Corbett et al. 1997a:470). West of Buldir is the final island group in the Aleutian chain, the Near Islands. Further west of the Near Islands, approximately 175 km from the Russian Kamchatka Peninsula, lie the Commander Islands, which were uninhabited until the 18$^{th}$ century (Veltre 1998:224).

[1] Identified by Veltre (2012) as Central Aleutians based on ethnographic data and *Unangan* linguistic divisions

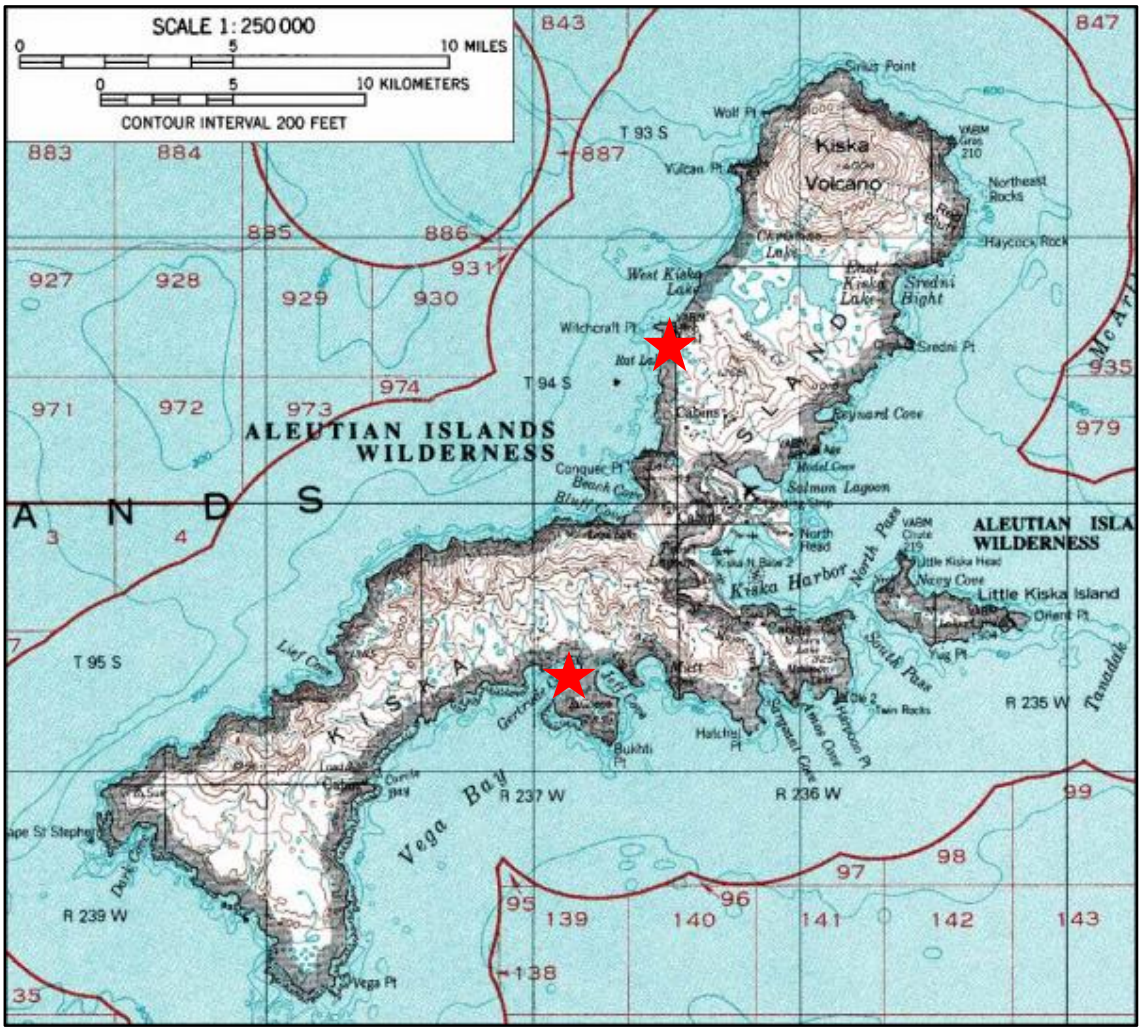



**Figure 2.3: Topographic map of Kiska Island with study sites indicated (modified from United States Coast and Geodetic Survey 1953)**

Kiska Island (Figure 2.3) is approximately 284.9 square km in area, 39.8 km long, and ranges from 2.8 to 11 km in width (Coats et al. 1961:563; Major et al. 2007:464). Topographically, the island is mostly poorly drained tundra, with small relatively shallow lakes across the island surface (Coats et al. 1961:567). Today the island is described as consisting of wet low-lying areas, higher inland areas, and vegetation free high elevation areas (Major et al. 2007:464). Geologically, the southern portion of the island consists of a submarine ridge (the Vega Bay formation) and the northern portion is dominated by Kiska

Volcano (Coats et al. 1961:563). The southern half of the island displays evidence of glaciation, but the northern half appears not to have been glaciated, and a veneer of volcanic ash coats the island (Coats et al. 1961:563). All the Rat Islands, including Kiska, are currently uninhabited; the island is within the Alaska Maritime Wildlife Refuge, which was established in 1913 (Berger et al. 2007:1899). The nearest permanent community is on Adak Island, the site of a non-operational Naval Base, currently home to a small community of approximately 200 people (Berger et al. 2007:1899).

There are limited terrestrial resources in the Aleutian chain and Kiska has no native terrestrial mammals; however both rats and foxes have been historically introduced, significantly influencing the island's ecosystems (Causey et al. 2005; Williams et al. 2003; Major et al. 2007). Rats (*Rattus norvegicus*) were either introduced in the 18th century from Japanese vessels (Funk 2010:10; Black 1984:52 referring to Rat Island) or are a product of WWII occupation (Bond and Brake 2008:3). Arctic Foxes (*Alopex lagopus*) were intentionally introduced beginning in the mid-18th century, and reached a peak in the early 20th century (Williams et al. 2003:175). The Russian-American Company enacted a program to introduce foxes in 1761 and there is record of them in the Rat Islands as early as 1825 (Funk 2010:10).Without any natural predators on the islands both foxes and rats thrived, and as invasive species significantly altered the ecology of the island. For example, there is evidence of increased predation causing an interruption in the breeding patterns of auklets (*Aethia* spp.) contributing to the rapid decline of avifauna beginning in the late 18th and early 19th centuries (Bond and Brake 2008:3; Major et al. 2006; Williams et al. 2003:175).

Archaeological work on Kiska Island has been limited, primarily due to the logistical issues involved in gaining access, providing for a crew on the isolated island, and conducting research in the remote area with continuously rainy and windy conditions. In general, the archaeological investigations on Kiska have been limited to reconnaissance and surveys and the archaeological record of the island is relatively unknown (Funk 2011:43).

### 2.2.1 Witchcraft Point (KIS-005)

Witchcraft Point is located on the northwestern edge of the Island, on the Bering Sea side (Figures 2.3 and 4.1). Witchcraft Point refers to a group of cultural features (n=96) situated on a promontory 15 m ASL, above a sandy beach, near the base of Kiska Volcano (Funk 2010:33; 2011:43). The site was investigated by Hrdlička in 1936 and was recorded to be approximately two metres in depth (Funk 2011:43). The site was later visited by the Bureau of Indian Affairs and was designated as three distinct sites (KIS-005, KIS-032, KIS-033) (Funk 2011:43). Of these sites this research project is based on field excavations completed at KIS-005. The site has been substantially disturbed from WWII military activity (Funk 2011:43) and prior to MUN's excavations had not been radiocarbon dated.

### 2.2.2 Gertrude Cove (KIS-010)

Gertrude Cove is a designated safe harbour located on the Pacific Ocean side of the island towards the south-central end (Figure 2.3 and 4.1). KIS-010 is located on the southern

shore of Gertrude Cove on a large rise approximately 5 m Above Sea Level (ASL), above a cobblestone beach (Funk 2010:34). The site has previously been investigated by the Bureau of Indian Affairs and the 2009 Rats and Birds Project (Funk 2011:43). The Rats and Birds crew excavated one test pit at a disturbed area towards the northern (cove side) end of the site (Funk 2011:45). The surface of the midden is covered in depressions ranging from large and semi-rectangular to small, deep, and circular. The midden surface is covered with artifacts from *Unangan* occupation and WWII activity, as well as with faunal material. As a designated safe harbour there is potential for a relative increase in traffic and evidence of looting has led to the necessity for archaeological assessment in the area (Funk 2010:34; Ian Jones personal communication 2012).

### 2.3 The *Unangan* of the Western Aleutians

A brief overview of the *Unangan* of the Western Aleutians is provided here to situate the study. This summary oversimplifies and undermines the complexity and dynamism of Aleut pasts as well as the complex archaeological record of the Aleutian Islands. Moving away from the materialist and colonial history of research in the region, current archaeological and anthropological work is aiming to increase the agency of humans, landscapes and human and environmental interactions (Corbett and Funk 2012:1). This is being completed through increasingly detailed site, island, and island group studies as well as through the integration of these studies to create larger, non-localized datasets and interpretations (Corbett and Funk 2012).

Approximately 9000 years ago the island chain was inhabited in an east to west migration, with evidence of about 3000-3500 years of human occupation in the far

western islands (Hatfield 2010:526; Veltre and Smith 2010:488; West et al. 2010:482). Prior to the historic period, the archipelago was home to a minimum of 9000 to 15 000 people (Corbett et al. 2010:1) and a maximum of 40 000 (West et al.2007:48; Frohlich 2002:65; but see Dall 1877:45 citing 50000). By the late 19th century, there was an estimated 2000 *Unangan*[2] living throughout the island chain (Dall 1877:45; Frohlich 2002:65). The *Unangan* are generally described as a specialized marine adapted people, and their maritime orientation is evident in both the material culture and faunal remains of the archaeological record (McCartney and Veltre 1999:505; Veltre 1998).

The archaeological record indicates that the first inhabitants of the islands arrived with this maritime adaptation; the Aleutian Tradition of 3000 BP represents the peak manifestation, which is characterized by a further developed and specialized sea mammal hunting adaptation (Corbett et al. 2008:45; McCartney 1984:121-122). The earliest recorded occupation of the Rat Islands is on Amchitka Island, and people arrived on the island with a stylistic complexity and variation in tool assemblage that is maintained over time, only sustaining minor stylistic changes over the 2500 years of habitation (Desautels et al. 1971:348).

McCartney and Veltre (1999:505-506) describe the "Aleut pattern" as almost exclusively coastally oriented, and significantly impacted by the constraints of the Aleutian environment, but as varying from island to island. Settlements are primarily coastal and ideally situated for protection and resource acquisition, ranging from large coastal villages to small resource specific camps (Corbett et al. 2008:44; West et al.

[2] *Unangas* or *Unangax* is used today to refer to central and western Aleut groups (Veltre and Smith 2010:488).

2007:49; Veltre and Smith 2010:488). However, as Funk (2010:9) points out, the system of settlement would have been complex, involving cultural constructions and travel across both the land and seascapes. Ocean travel was an integral component of *Unangan* life and was completed in *baidarkas* (skin kayaks sewn around wood and bone frames), ideally designed for open ocean travel, hunting, and fishing (Jochelson 1968 [1933]:25; McCartney and Veltre 1999:505-506).

Houses in the Aleutians were generally semi-subterranean *barbarras* made of stone, driftwood, or whalebone with turf covering (Black 1984:64; Dall 1877:46; McCartney and Veltre 1999:505; West et al. 2007:49). Dwelling size and interior layout varied throughout the chain and over time (Black 1984:64; Coltrain et al. 2006). Seasonal food storage was integral, and raw food was commonly consumed; cooking was completed on stones with sea mammal oil, dry grass, and driftwood used as fuel (Black 1984:53; Jochelson 1968[1933]:21). Clothing was made of bird and sea mammal skin with gut parkas (*kamleis)* used as waterproof shells (Black 1984:53; Jochelson 1968[1933]:10; McCartney and Veltre 1999:506).

The *Unangan* are archaeologically characterized by their exclusively marine economy, but recent investigations in island interiors have demonstrated that there is a greater variety in settlement patterns and habitats of exploitation than has previously been assumed (Hanson and Corbett 2010). Additionally, as Funk (2010:8) points out the common tendency to assign site importance and category based on size (e.g. McCartney 1977:65), which emphasizes large coastal villages, is based on limited field evidence and without an understanding of site connectivity over time and space.

Oral narrative, mtDNA analysis, skeletal morphological variation, and material culture suggest that there were potentially two distinctive migrations into the Aleutians, however further research is required, especially in the western Aleutians and Rat Island group (Coltrain et al. 2006; Corbett et al. 1997a; Hatfield 2010:544; Hrdlička 1945; West et al. 2007). Migration occurred in an east to west movement; with a population movement into the island chain at around 9000 BP, and approximately 1000 AD/BP, which is accompanied by evidence of widespread cultural change throughout the region (Coltrain 2010; Corbett et al. 1997a:463; West et al. 2007:49-50). These migration periods are also correlated with periods of glacial advancement and changing climatic conditions (West et al. 2007:51)

The second migration wave into the island chain, a component of a Pan-Alaskan cultural movement, is marked by the Late Aleutian Trait Complex (Funk 2010:7; Corbett et al. 1997a). Other identifiable cultural changes at this time include a shift from single family to larger multifamily semi-subterranean dwellings (Davis and Knecht 2010), and changes in mortuary practices (Coltrain et al. 2006:545), which have been linked to increases in social complexity (e.g., Fitzhugh 2003). Additionally, dietary and stone tool analyses (e.g. Coltrain 2010; Hatfield 2010), indicate a change in economic strategy as the later population (Neo-Aleut) demonstrates different consumption patterns, with a greater emphasis on larger marine mammals (Coltrain 2010:395). This period is also marked by the introduction of ground slate and iron tools and an increase in inter-island cultural identity and expression (Funk 2010:7; for iron use see Black 1984:53, 56; Jochelson 1968[1933]:21-23). Further radiocarbon dates are valuable in adding to and

refining this chronology, especially in the Rat Islands where evidence is lacking to indicate the presence of two distinctive migration waves.

Each cluster of islands in the Aleutians (Figure 2.2) is considered a separate *Unangan* polity. Characteristics of each polity are archaeologically identified mostly through bone tool kits and burial patterns (Corbett et al. 1997a:467). There were both violent and peaceful interactions between the island groups, including war, trade, and marriage (Corbett et al. 1997a:467; Black 1984:43). According to ethnographic accounts from the 1820s (Veniaminov 1984 [1886]), warfare was extensive (Corbett et al. 1997a:467; Black 1984). Historical and ethnographic work indicates that the polities, although acting as social barriers, were continuously crossed for a variety of reasons including trade, marriage, and war (Funk 2010:9).

Black (1984:45) identifies the cultural divisions or polities of the Aleut as reflections of identifiable linguistic divisions. However, she points out that within each major linguistic division there were also independent polities, or more localized groups, which were organized by patrilineal kinship (Black 1984:45). When the Russians entered the Aleutian chain in 1741, three distinct Aleut dialects were identified throughout the central and western region; however, this is still poorly understood and most likely underestimates the dialectic diversity of the region (Veltre 2012:36). Amchitka Pass, which separates the Rat Islands from the Central Aleutians, is a distinctive geographical divider, and is also identified as a linguistic and cultural divider (Black 1984:42). Russian explorers in the 18$^{th}$ century recorded that Rat Islanders spoke a dialect most similar to that spoken by the inhabitants of Attu Island (Black 1984:53).

Rat Island *Unangan* are identified as *Qagus, Qaxun*, or *Qaĝun* (Black 1984:1,52). Russian explorers in the 18th century identified the population of the Rat Islands as highly mobile, shifting from one island to another, with the population base at Amchitka and Kiska Islands (Black 1984:52). Although more generalized Aleut traits are considered to have been shared throughout the island chain, the Rat Islands are identified as a distinctive *Unangan* polity (Funk 2010:9; Black 1984:45). Further work towards the western end of the island chain will continue to contribute to the understanding of the unique characteristics of Rat Islanders and of the nature of interactions with their neighbouring Near Islanders and Central Aleutian groups.

Fishing methods include the use of hook and line technologies as well as nets and weirs and fish spears (Cook 1784 cited in Hrdlička 1945:39; Jochelson 2002[1925]). Near shore fishing was conducted by hook and line and nets, with offshore fishing conducted by *bairdarka* with hook and line (McCartney 1984:133; Tolstykh 1761 cited in Hrdlička 1945). Line was made of kelp or sinew and could be stretched up to 274 m (150 fathoms); hooks included small, single hooks as well as large composite styles dependent on species and depth (Bank 1952b; Jochelson 2002 [1925]; Tolstykh 1761 cited in Hrdlička 1945). Jochelson (2002:89 [1925]) provides an example of a specific compound fish hook (*U'tax˙/aqa'nax˙*), the parts include: a curved hook (sea lion tooth), a curved point (sea lion tooth), a line of plaited sinew, a sinew thread to attach bait, a small root wrapped in bark that attracted specific fish, a quill of bird bone that bound the two sea lion hook components, a bird (cormorant) quill to affix bait, and sinew threads with attached bark pieces to prevent the sinew from sliding.

The *Unangan* harvested both pelagic and near shore fish species and there is ample evidence throughout the region for offshore fisheries, of which cod was one of the targeted species (Maschner 2012:138; West et al. 2011:80). For offshore fishing activities *baidarkas* were an integral apparatus. The efficacy of these vessels in the Aleutian environment, their superb design and manufacture, and the renowned skill and abilities of the *Unangan* is acknowledged in ethnographical literature as well as in terms of modern kayak manufacturing (McCartney and Veltre 1999:506; Robert-Lamblin 1980; West et al. 2007:48). For example, according to one account from the late 18$^{th}$ century, the boats and paddlers evoked awe "they [baidars] are beautiful; to me they appear so beyond anything that I ever beheld" (Sauer 1802:157). The author continues to remark that the boats not only appear perfectly constructed but that the skill and agility of the paddlers far surpass any counterparts, creating the illusion of amphibious humans (Sauer 1802:157). Sauer (1802:157) estimates that in moderate conditions paddlers travelled about 16 km (10 miles) an hour, but noted that the *baidarkas* were still well used during gale force winds. The heavy reliance on sea mammals as a main component of the *Unangan* maritime adaptation demonstrates the extensive skill and knowledge associated with *baidarka* based fisheries and the adeptness with which the inherent risk of offshore fishing activities in the region were addressed (e.g. Jochelson 2002:121[1925]).

Pacific cod presence is often used as an indicator of summer occupation in the Aleutians, and harvesting is considered to primarily occur during spring and summer when cod reputably move inshore (e.g. Funk 2011; Knecht and Davis 2008; Lefèvre 1997; West et al. 2012). The *Unangan* harvested both near shore and pelagic species, and evidence for deep sea fisheries extends to at least 4000 BP in the eastern end of the island

range (West et al. 2011:80; Workman and McCartney 1998:365; Laughlin and Marsh 1951). There has not yet been work to further delineate the seasonal variation in fishing strategies, as has been completed for the areas of the Atlantic (Carlson 1986; Moss 2011:151). Assigning site seasonality and seasonal patterns of occupation in the western Aleutians continues to be a challenge, and developing a better understanding of seasonality continues to be a component of ongoing research (e.g. Funk 2011:40; Lèfevre 1997).

### 2.4 Overview of Historic Period: Russian Arrival and WWII Activity

The movement of Russian explorers and fur traders into the Aleutian chain, followed by Orthodox missionaries, marks the beginning of the historic period in the Aleutians (Black 1984:1; West et al. 2007:49). Russian explorers, Bering and Chirikov, first entered the Aleutians in 1741 (Black 1984:72; Jochelson 1968[1933]:1). The introduction of the Russian fur trade and its associated violence in the 18th century, as well as the subsequent effects of industrial scale resource exploitation, has significantly impacted local Aleut people, culture, economy, and environment (Corbett et al. 2008:69; McCartney and Veltre 1999:505; West et al. 2007:49).

This phase of Aleutian history is commonly divided into the early post-contact period (1747-1799) and the Russian-American Company period (1799-1867, but not legally established until 1823) (Black 1984:1, 46). These periods are characterized by intense marine mammal (sea otters, *Enhydra lutris*, and fur seals, *Callorhinus ursinus*) exploitation, violence, the forced displacement of *Unangan* groups by Russian fur traders, and the entrance of the Aleut into the market economy (West et al. 2007:49). Extensive

ecological changes are also recorded as occurring throughout the archipelago during this time period (Frohlich 2002:63; West et al. 2007:49).

Reports of the activities of the Russian fur traders indicate at the violence that marked this period, and the resultant widespread social and ecological changes, including: forced relocation, brutality, abduction, and extensive sea otter exploitation (Sauer 1802:161,171; Veniaminov 1984[1840]:198). Later WWII activity in the region resulted in further alterations of the sociocultural and physical landscapes, including the United States government's forcible relocation of the remaining *Unangan* communities to internment camps in mainland Alaska, often under inhumane conditions (e.g., L.C. McMillan to E.C. Johnston, letter, 24 July 1942, Records of the United States Fish and Wildlife Services, Anchorage; Aleut American women, petition, Records of the United States Fish and Wildlife Services, Anchorage). Currently, the western Aleutians and most islands in the archipelago are uninhabited and an estimated few hundred Aleut continue to live in the Aleutians (West et al. 2007:49; West et al. 2010:481).

The Russians entered the Rat Islands between 1753-1763 (Black 1984:74-83; Funk 2010:10), although Kiska Harbour acted as a draw to early Russians because of the naturally ideal harbour, the Rat Islands were mostly considered unprofitable to the Russians by the 1760s (Funk 2010:10; according to Black 1984:82 uninhabited by 1758). By the end of the 18$^{th}$ century, the Rat Islanders were moved out of the region to other islands to participate in the Russian fur trade (Funk 2010:10). Russian reports indicate that Rat Islanders were moved from the region primarily to Atka, but also to Adak and Attu islands; as well, in 1768 numerous central and western islanders were taken to the Pribilof Islands for hunting (Black 1984:42; Funk 2010:10; West 2012:3). According to

accounts from the Russian navigator Vasil'ev (1984:158) from 1811-1812, throughout the Rat Islands there were two small habitations totalling 11 people. However, Funk (2010:10) reports that both Kiska and Amchitka Islands were sporadically inhabited until 1867.

As Atalay (2006) and Whitridge (2008) demonstrate, cross-cultural interactions are variable and the archaeological tendency is to generalize these encounters, over-emphasizing the agency of European arrivals, and presenting a hegemonic and asymmetric account (Whitridge 2008:291). Although this undoubtedly occurs in discussions of *Unangan*-Russian interactions, including this research's reliance on Russian over *Unangan* sources, the 18th century ethnographic record of the western Aleutians suggests the variety and complexity of these relationships (e.g., compilation by Black 1984). However, emphasis generally seems to be given to accounts of violence and animosity, which occurred from both sides. One example Black (1984:10-11) provides, transcribed from the reports of early Russian explorers (*Polnskii*), is of the interaction between *Unangan* men attempting to ransom for the return of their son after a conflict and the subsequent capture, brutal torture, and death of two of the *Unangan* men aboard the Russian vessel. The 18th century Russian voyager Lisenkov, specifically characterizes the Russian relationship with Rat Islanders as tense and violent. He describes the Rat Islanders as meeting both Russian and Japanese ships, boarding the boats in gestures of good will where they would assess the crew and the contents, offer encouragement to land at good harbours, and then attack (Black 1984:53-54).

Following this period of Russian-*Unangan* interaction there is limited habitation and activity in the Rat Islands; however, Kiska Harbour acted as a trading point for otter

hunting and fox trapping from 1870-1911 (Funk 2010:10). By 1881 there were no remaining *Unangan* villages in the Rat Islands and only one village remained in the western Aleutians, on Attu Island in the Near Island group (West 2012:4; Black 1984:105).

Kiska Island, along with Attu Island, was occupied in 1942 by Japan (approximately 500 men) as a component of their amphibious task force in the western Aleutians. At the time, the only inhabitants of the island were personnel attending the U.S. weather stations on the island (Verbeck 1945:1). By August, there were an additional 1500 Japanese personnel on the island, and in September of 1942, the Japanese battalion that had held Attu for the summer moved to Gertrude Cove (Verbeck1945:2).

Throughout the Japanese occupation of Kiska, there was sporadic and uncoordinated U.S. bombing missions across Kiska whenever weather permitted intensifying over time and due to loss of supply routes, which significantly altered the island's landscape (Verbeck 1945:2-3). The Japanese began evacuations of Kiska in July of 1943, and when American and Canadian assault troops landed in August, there was no Japanese presence identified on the island (Verdeck 1945:4). This extensive WWII activity and the largely uncoordinated bombing efforts significantly altered the ecosystems and archaeological record of Kiska, while adding another phase to the occupational history of the island.

### 2.5 Previous Archaeological Works in the Region

Archaeological investigations have been conducted in the Aleutians since the 1870s (e.g., Dall 1875); however, the scope of work has been relatively limited and few thorough excavations have been completed (Corbett et al. 2010:17). A valuable resource is the ethnographic data collected during the 18th century by Russian explorers, fur traders, and Orthodox missionaries (Corbett et al. 2010:1). The logistical requirements related to excavating in the western Aleutians, even in comparison to the eastern end of the island chain, are a key element in limiting archaeological work. This continues to be an issue and logistics is a prime consideration in excavations (Corbett et al. 2010:3; Frohlich 2002:64-65).

Three main contributors to the early interpretation of Aleutian prehistory are Dall, Jochelson and Hrdlička (Corbett et al. 2010:19). As a component of hydrographic and geodedtic surveys between 1871 and 1874, Dall excavated a number of archaeological sites throughout the island chain (Corbett et al. 2010:17; Dall 1877; Veltre 2012:37). Dall's excavations included work on Amchitka, Adak, Atka, and likely Kiska and Little Kiska islands (Corbett et al. 2010:17: Dall 1877:44; Veltre 2012:37). Dall's work is considered pioneering in his consideration for stratigraphic association (Corbett et al. 2010:19). Unlike his later counterparts in the region, Dall was cognizant of the importance of stratigraphy to the interpretation of archaeological material and identified many components of Aleutian prehistory that uphold today (e.g. multiple westward migration waves) (Dall 1877:48). By completing trench excavations through middens, Dall developed a three stage evolutionary paradigm for the Aleutians, which has since been reworked (Corbett et al. 2010:19; Dall 1877:49; Veltre 2012:37).

Further investigations in the region were not completed until over thirty years later. The anthropological division of the Imperial Russian Geographical Society, led by Jochelson, conducted exploration and excavations in the region in 1909 and 1910 (Jochelson 1968[1933]: introduction; Corbett et al. 2010:17; Veltre 2012:37). Other than archaeological work, they also conducted anthropomorphic studies and recorded oral histories (Jochelson 1968 [1933]; Veltre 2012:37). Jochelson's crew excavated middens on Attu, Atka, Umnak, and Unalaska (Corbett et al. 2010:1). These investigations often lacked any stratigraphic or other contextual information as the focus was primarily artifact collection (Corbett et al. 2010:1). Although this work provides a significant contribution to the history and prehistory of the region, the lack of context and associated records limits the interpretative value of the material (Veltre 2012:38). Jochelson's contributions to the interpretation and understanding of prehistory in the region include: his dismissal of Dall's simplified three stage evolution, his acknowledgement of the significant adaptive quality required of the Aleut to successfully thrive in the Aleutian environment, and his recognition that there was relatively little cultural change over time demonstrable in the archaeological record (Veltre 2012:38).

In 1936 and 1938, excavations were continued in the western Aleutians (including Kiska Island) by Hrdrilčka (1945:1), a physical anthropologist with the Smithsonian Institute. The primary focus of these investigations was the recovery of human skeletal remains, with little attention to provenience and other materials. However, Hrdrilčka did take note of the lithic and bone tool industries that he encountered (Corbett et al. 2010:17; Hrdrilčka 1945; Veltre and Smith 2010:494).

From WWII to the 1971 Alaska Native Claims Settlement Act there was limited archaeological work conducted in the region, and of the work that was completed most was survey based (Veltre 2012:38; Veltre and Smith 2010:494-496). The next large scale survey and excavation in the western Aleutians occurred in the 1960s as a component of an environmental assessment prior to nuclear weapons testing on Amchitka Island (Desautels et al. 1971:i). This marked the first attempt at fully archaeologically documenting a large Aleutian island, and led to the identification of 86 archaeological sites (Funk 2010:26; Veltre 2012:39) (78 identified by Desautels et al. 1971:22).

The work from this post war period is generally considered limited and arbitrarily geographically constrained. This has contributed to ambiguity regarding cultural contact, isolation, and regionalism, and has also prevented the development of a coherent, inclusive culture history of the region (Corbett et al. 2010:3). Additionally, the further isolated nature of the western Aleutians has proved challenging for archaeological projects, further limiting the scope and nature of investigations (Corbett et al. 2010:3).

More recently, the Western Aleutians Archaeological and Paleobiological Project (WAAPP) began a twelve year project starting with excavations at Buldir Island in 1991 (Corbett et al. 1997b; Corbett et al. 2010; Corbett 2011:4). WAAPP's main goals are to look specifically at Near Island Aleut characteristics and cultural development, as well as to identify changing environmental conditions (Corbett 2011:4). WAAP developed as a result of an increase in biologically focused research on archaeological material from the Aleutians, and the recognition that the limited excavation techniques and recording of early projects have restricted current analyses. Specifically, Causey's (Causey et al. 2005; Corbett et al. 1997b) analysis of the distribution and abundance of bird species over time

was significantly hampered by the collection methods of earlier investigations and presented the need for faunal samples with good provenience (Corbett et al. 2010:5).

The goals of WAAPP include documenting and defining the development of the distinctive western Aleut culture as well as documenting Holocene environmental changes (Corbett et al. 2008:45). WAAPP has further refined their cultural ecological and biological approaches to address a few main research areas. These include an investigation of the region's ecosystems through time to better understand the impact of the historic introduction of alien species, and the shift to a market or commercial economy with industrialized practices (Corbett et al. 2010:16).

WAAPP investigations of Near Islands archaeological material, have demonstrated the distinctiveness of Near Island archaeological assemblages (Corbett et al. 2010:18). Although speculative, it seems that a similar increase in the research of Rat Island material will also serve to further demonstrate the distinctiveness of Rat Islanders. In the preliminary lithic analysis completed for a component of this research project, a distinction was seen between Near Island lithic assemblages and the assemblage recovered from test units at Gertrude Cove, Kiska Island (Young-Boyle 2012).

In 2009, an archaeological reconnaissance was completed in the Rat Islands as a component of the Rats and Birds Project. The aim of this on-going research is to identify changes in Aleut subsistence remains and cultural material from the prehistoric to historic periods with a focus on bird remains (Funk 2010:1). This reconnaissance consisted of both test pit and surface surveys of sites in the Rat Islands. The project included a survey of archaeological sites on Kiska Island, including the midden sites at both Witchcraft Point and Gertrude Cove. Funk (2010:33-34) identifies both sites as having recently been

substantially altered by erosion (Witchcraft Point), and extensive looting (Gertrude Cove). Through two short field seasons of survey and testing (2003 and 2009), the Rats and Birds project was able to determine that Kiska, as well as Rat and Amchitka Islands, were far more densely populated than the limited nature of previous work had demonstrated (Funk 2010:26). As well, Funk determined that site types on the islands have much more variety than had previously been assumed with the focus on visible coastal middens (Funk 2010:26).

In addition the archaeological research indicated above, Jones (Memorial University) has been studying seabird ecology and evolutionary biology in the western Aleutians, with a project on Kiska Island since 2001 (e.g. Major et al. 2007; Major et al. 2013). Jones and other seabird biologists (e.g. Causey et al. 2005) are currently working with archaeologists to extend their ecological understanding of the Aleutians into prehistory with a focus on the impact of introduced rats and foxes on the islands' seabird populations. This thesis is a direct result of Jones' efforts to incorporate archaeological work into his ecological studies on Kiska Island. Stemming from this amalgamation of archaeological and biological research, palaeoclimate reconstructions are being developed for the region (e.g. Causey et al. 2005; Corbett et al. 2008). The inclusion of climatic data at the tight temporal scale provided by archaeological fish otoliths has the potential to substantially contribute to this discussion of the Aleutian palaeoclimate, particularly by providing highly localized climatic data.

Overall, studies in the Aleutians have demonstrated changing environments and human cultural groups over time (West et al. 2007:47). Despite the focus on palaeobiologcial and palaeoenvironmental studies the data and interpretations are not

comprehensive, partly due to the limited nature of the work (as demonstrated by West et al. 2010; Veltre 1998; Corbett et al. 1997a, 1997b, 2010; Funk 2011), which has significantly skewed interpretations (West et al. 2007:47). Current archaeological analyses aim to deepen our understanding the Aleutian Islands, with a focus on the study of population movements, western migration, and palaeoenvironmental reconstructions (Veltre and Smith 2010:500).

## Chapter 3: Otoliths as Environmental Recorders

Otoliths are paired inner ear structures in teleost fishes that aid in balance and hearing (Popper et al. 2005:498). They are composed primarily of calcium carbonate, most commonly in the form of aragonite (Campana 1999:263; Elsdon et al. 2008:298; Harvey et el. 2000:1). Of the three pairs of otoliths (lapillae, asteriscae, sagittae) the sagittae are the largest, the most species specific, and contain the most distinctive growth patterns (Andrus and Crowe 2002:291; Disspain et al. 2011:1842; Harvey et al. 2000:1). As a result, sagittal otoliths are the most commonly analyzed, and the most archaeologically visible (West et al. 2012:3277). By accreting material from the inner ear fluid, which is in physiochemical equilibrium with the surrounding water, otoliths grow in concentric layers outwards from the core or nuclei at a constant periodicity for the duration of the fish's life (Matta and Goetz 2012:5). As a result the analysis of otoliths, which crosses various disciplines such as fisheries biology and zooarcaheology, provides significant insight into the fish's life history, ambient water conditions, and the relationships between fish behaviour, climatic conditions, and human occupation and harvesting patterns.

### 3.1 Otolith Growth

Fish otoliths develop by accreting minerals from the surrounding inner ear fluid (endolymph) throughout the duration of the fish's life (Campana 1999:264). On a daily basis protein and crystalline material is accreted onto the surface of the otolith at a rate regulated by feeding, behaviour, and environmental conditions (Elsdon et al. 2008:298; Reitz and Wing 2008:63). This incremental growth occurs throughout the fish's life with

development beginning in embryo; the nucleus of the otolith forms at hatching or first feeding, and consistent daily increments continue to develop throughout the fish's life, but in decreasing width as the fish ages (Andrus and Crowe 2002:29; Morales-Nin 2000:57-58).

The increments form based on differences in the calcium secretion rate, and although these increments vary in width based on temperature and feeding behaviour, the periodicity is constant, providing a reliable chronological record (Morales-Nin 2000:61). These increments are expressed as alternating translucent and opaque bands, based on levels of continuity in aragonitic growth (Andrus and Crowe 2002:291; Morales-Nin 2000:56). The material is deposited in concentric bands, building outwards from the core of the otolith so that the outermost otolith margin is deposited most recently, representing the environmental conditions experienced by the fish closest to the time of capture as demonstrated in Figure 3.1 (Hufthammer et al. 2010:81; Matta and Goetz 2012:5, no scale provided).

**Figure 3.1: Thin sectioned Pacific cod otolith illustrating the concentric growth pattern (modified from Matta and Kimura 2012: i)**

Generally, the accumulation of increments is represented within the otolith by two macroscopic concentric bands, one opaque (light) and one translucent (dark due to

transmitted light), reflecting one year of fish growth (Matta and Goetz 2012:5). Although there is variation between species, in general the otoliths of North Pacific fish have wider opaque zones associated with faster growth and narrower translucent zones representative of periods of slower growth (Matta and Goetz 2012:5). An increase in the rate of the fish's metabolism causes an increase in growth, which generally corresponds to an increase in water temperature and/or seasonal fluctuations (Høie et al. 2004:1048). As a result, opaque bands are generally referred to as summer growth and translucent bands as winter growth (Matta and Goetz 2012:5). These terms are used in this thesis for simplicity and to be consistent with the literature, however the terms are misleading by this oversimplification and cannot be used as seasonal identifies; they are representative of sub-annual fish growth patterns, which are influenced by various physiological and environmental factors. A major assumption within otolith growth studies is that the annular marks are reflections of yearly growth (Matta and Goetz 2012:6). Although growth in marine organisms is regulated by variation in oxygen, temperature, salinity, and the availability of nutrients, growth rate is not constant and there are a variety of factors that affect the rate of fish and otolith growth (Reitz and Wing 2008:77).

Although data is limited for the western Aleutians (see Section 6.2), Pacific cod in the western Bering Sea generally spawn at temperatures between 0-3°C and in the eastern Bering Sea mass winter aggregations occur at relatively warm and stable temperatures at about 4°C (ADFG 1985:321-322). These temperatures are maintained year round in the depths off Unimak Pass, which is maintained year round in the depths off Unimak Pass; bottom temperatures on the shelf in this area ranges from 0.2 to 4.5°C in the summer and drop below 0°C in the winter (Shimada and Kimura 1994). Generally, Northwest Pacific

Ocean and Bering Sea surface temperatures (SST) are characterized by strong seasonal variation, with winter temperature ranges of 0-2°C and summer ranges of 8-10°C (Max et al. 2012:3). This surface variation is followed by a severe drop in temperature to ~2°C within the first 120 m from the surface, with minimal variation from 120-400 m (~2-4°C) (Riethdorf et al. 2013). The Aleutian archipelago also has complex bathymetric and hydropgraphic conditions, which are heavily influenced by the ocean passes, which are poorly understood. The strong tidal currents play a vital role in regulating salinity, temperature, and mixing within the water column (Stabeno et al. 2005:52). Overall, analyses indicate that the bottom water conditions of the passes demonstrate annular variation in temperature but the deeper passes towards the western Aleutians are generally more stable with less variation (Stabeno et al. 2005). Bottom temperatures at the passes seem to vary annually by ~1.5°C, reaching seasonal maxima in September and minima in May (e.g. Tanaga Pass ~4 to 5.5°C).

In addition to annual marks, most otoliths also contain checks and sub annual marks, which are almost identical in appearance to annular marks but are reflections of other physiological and environmental factors (e.g., hatching, stress, habitat variation) (Matta and Goetz 2012:6; Morales-Nin 2000:58). The sensitivity of cod to other life events such as trauma, feeding, and fluctuating water temperatures can cause changes in band transparency that can be mistaken for seasonal variations (Ketchen 1970; Matta and Kimura 2012; West et al. 2012:3280). These sub-annular variations, known as checking and splitting, cause increased difficulty in aging and identifying season of capture; for example, Pacific cod have extensive checking in early life due to rapid growth, which causes aging issues (Johnston and Anderl 2012:27). Pacific cod are infamously difficult

to age due to this sensitivity and the presence of checks and other markers, and during stages of rapid growth multiple checks are often exhibited (Johnston and Anderl 2012:25; Ketchen 1970:1). There are identifiable tracers that an experienced reader, familiar with the species, can usually use to differentiate between checks and annular marks. As well, annular bands can often split causing the deposition of multiple translucent bands within one yearly cycle, and the use of a reading axis is integral in otolith aging because material is not deposited evenly throughout the otolith (Matta and Goetz 2012:6). Another difficulty arises with older fish; as the fish ages the annular banding becomes less distinguished and it is more difficult to differentiate between bands. Outer edge formation can be especially difficult to identify and is also the most pertinent in determining seasonality. For example, the development of a marginal translucent zone can be invisible causing the age reader to estimate the opaque zone as representative of season of capture (Matta and Goetz 2012:9).

Despite these challenges related to otolith growth interpretation, otoliths continue to be one of the main structures used for fish aging, and the only dependable methods for species such as Pacific cod, and the methods are continually being refined (Campana 1999, 2005; Helser 2013; Matta and Kimura 2012). As a result, age validation is a major component of otolith research and the addition of stable isotope analysis is one of several age validation methods that are constantly being reviewed and refined in an attempt to improve aging methods, especially for commercially significant groundfish species. To address these issues, this study collaborated with laboratories and personnel with training and experience in cod age and growth determination. The development of otolith geochemical analyses and aligning isotopic data with the annular growth structures has

further verified and contributed to the understanding of otolith growth and the representativeness of annular marks (e.g. Kastelle et al. 2012).

### 3.2 Otolith Composition

As biogenic calcium carbonate structures, otoliths incorporate oxygen and carbon isotopes from the surrounding water and are metabolically inert after formation, acting as environmental recorders for the duration of the fish's life (Campana 1999:275; Elsdon et al 2008:298; Hanson et al. 2010:2491). Minerals are accreted from the endolymph fluid and deposited onto the surface of the otolith, which is permanently retained and unaltered (Campana 1999:264; Elsdon et al. 2008:298; Hanson et al. 2010:2491). Otoliths are generally composed of aragonite, a polymorph of calcium carbonate, which is relatively (97%) chemically pure (Campana 1999:264-265; Popper et al. 2005:503). A variety of elements have been identified within the otolith matrix, but these make up less than 1% of total otolith composition (Campana 1999:264). Aberrant sagittal otoliths can also exist in the form of vaterite, another calcium carbonate polymorph, and the depositional environment can also alter the aragonitic structure of the otolith through crystallization or re-crystalization, creating a more calcitic material and altering the isotopic composition of the otolith (Campana 1999:265; Campana 2004:3).

As originally presented by Urey (1947:568-569) and McCrea (1950:857), the fractionation of oxygen isotope ratios in carbonates is temperature dependent. The oxygen isotope values of otoliths have since been demonstrated to be in physiochemical equilibrium with ambient water (Campana 1999:275, 287; Gao et al. 2001; Hanson et al. 2010:2491; Høie et al. 2004; Thorrold et al. 1997). The otolith retains a record of the

chemical composition of the ambient water, and when directly correlated to the annular growth bands of the otolith, this presents a detailed chronology of the fish's environment (Campana 1999:264). Therefore, variations within $\delta^{18}O_{otolith}$ reflect environmental changes and serve as a proxy for the chemical composition and temperature of ambient water (Andrus and Crowe 2002:291; Gao et al. 2005:342).

The $\delta^{18}O$ of otoliths in combination with known ambient water $\delta^{18}O$ is used to determine water temperature and salinity at the time of otolith deposition (Hanson et al. 2010:2491). Water temperature reconstructions have been demonstrated to be accurate to within 1°C (Høie et al. 2004:1046; Thorrold et al. 1997:2909). Archaeologically, this reconstruction is generally not possible, because the chemical composition of past water is unknown. However, through an analysis of the relative $\delta^{18}O$ values within an otolith it is possible to reconstruct relative changes in water temperature over time (e.g. West et al. 2012), and to independently verify the season of fish capture if the outermost otolith band remains intact (e.g. Hufthammer et al. 2010).

Through the analysis of $\delta^{18}O$ and $\delta^{13}C_{otolith}$, the migratory behaviours of the fish can be better understood (Hanson et al. 2010:2491; Elsdon et al. 2008). However, unlike $\delta^{18}O$, $\delta^{13}C$ values are not in relative equilibrium with ambient water and carbon uptake is significantly influenced by a variety of factors, including diet, metabolism, and migration, the characteristics of which are still relatively unknown (Gao et al. 2001:445; Jamieson et al. 2004). Due to the added complexity related to $\delta^{13}C$ precipitation, and the focus on fish migration, which is not a component of this research, this study focuses on $\delta^{18}O$. However, the $\delta^{13}C$ values are presented and briefly discussed.

$\delta^{18}O$ values are inversely related to water temperature; as temperature decreases the heavier $^{18}O$ is preferentially incorporated into the otolith over the lighter $^{16}O$ (Hufthammer et al. 2010:81; Jones and Campana 2009:1503). This fractionation enriches or depletes the ratio of $^{18}O$:$^{16}O$ (expressed as $\delta^{18}O$) based on environmental conditions, and it has been clearly demonstrated that temperature is the determining factor in the variation of $\delta^{18}O$ between seasonal and sub-annual bands within an otolith (Gao et al. 2001:451; Reitz and Wing 2008:78). Although the relative physiochemical equilibrium has been well established, the physiological filtering process between the otolith and the ambient water complicates the interpretation of $\delta^{18}O$ values. Further investigations of the temperature dependence of otolith precipitation have identified significant patterns of variation in precipitation and growth rate (Campana 1999:264).

For example, through the controlled experimentation of Norwegian stock Atlantic cod (*Gadus morhua*), Gao et al. (2001) confirmed an inverse relationship between $\delta^{18}O$ and temperature for the first four years of the cod's life, with the largest seasonal shift at 1-1.5 years, and a subsequent decrease in amplitude with increasing age (Gao et al. 2001:448). This analysis also demonstrated that seasonal $\delta^{18}O$ variation falls into two categories determined by maturity and migration patterns: up to four years of age $\delta^{18}O$ varied based on ambient temperature, and after four years $\delta^{18}O$ remained relatively constant (Gao et al. 2001:450). At four years of age cod mature and remain at or near ocean bottom, with minimal movement within the water column, where temperature variation is relatively minor (Gao et al. 2001:451). Therefore, the development of constant $\delta^{18}O$ values can be identified as a marker of fish maturity.

The authors also hypothesize that after maturity aragonite is deposited mainly during the summer, with $\delta^{18}O$ values accurately reflecting summer temperatures but not winter temperature patterns (Gao et al. 2001:451). These results are further validated in a study looking at Pacific cod (*Gadus macrocephalus*) (Gao et al. 2005) demonstrating a wider application (beyond species or stock specific), allowing for greater confidence in applying these hypotheses to the interpretation of Aleutian stock Pacific cod $\delta^{18}O_{otolith}$ values in this study.

Additionally, through controlled experimentation on a sample of Atlantic cod (*Gadus morhua*) with known temperature histories, it has been demonstrated that the summer temperatures early in a cod's life are accurate but as the cod ages, the $\delta^{18}O$ signals cause an underestimation of temperature (Høie et al. 2004). As well, in general winter temperatures seem to be overestimated (Høie et al. 2004:1042). This appears to be a result of reduced sampling and attenuation of $\delta^{18}O$ values as the fish ages. Despite these caveats, the experiment also demonstrated that the precision of inferring ambient temperature is ± 1°C of recorded temperatures (Høie et al. 2004:1046).

Therefore, temperature can be accurately reconstructed from otolith oxygen isotope ratios if the isotopic composition of the water is known, although there are other influential factors that must be recognized (Campana 1999:276; Hanson et al. 2010:2491; Thorrold et al. 1997). When applying this concept to archaeological material, an accurate estimation of water temperature is not possible without the isotopic signature of the water. Fortunately, this eliminates the assumptions required for the calculation of actual temperature values, and minimizes the need for fractionation equations designed to take into account variables related to geography, temperature, and salinity (Hanson et al.

2010:2496; Hufthammer et al. 2010:83). For palaeoclimate applications, the cycle of variation in $\delta^{18}O$ values (inter and intra-otolith) demonstrates seasonal variation and allows for the inference of relative water composition over time (Hufthammer et al. 2010:75).

### 3.3 Pacific Cod Behaviour

Pacific cod are a cold water, transoceanic groundfish species; they move from deep, cold water to shallower, warmer water in the late winter, spring, or early summer (Berger et al. 2007:1899; Moss 2011:155; Thompson and Dorn 2003:128). Adult cod migrate seasonally based on spawning and feeding behaviours (Johnston and Anderl 2012:25). This seasonal migration consists of annual congregations of spawning stocks at depths of up to 500 m, followed by dispersal for feeding (Gao et al. 2005:335; Hart 1988). Pacific cod habitat ranges from as far north as the Chukchi Sea to the southern limit at Santa Monica Bay in California (Johnston and Anderl 2012:25; Love 1991). In comparison to other groundfish species of the North Pacific cod are fairly fast growing with short life spans, with modern data indicating a maximum of 17 years (Johnston and Anderl 2012:25). Pacific cod's preference for stable water conditions is well demonstrated, and a maximum range within a cod's lifetime is approximately 6°C (ADFG 1985:321-322).

Juvenile cod live within kelp and eelgrass communities in near shore environments, primarily for protection from predators and access to food sources (invertebrate larvae and bivalves), with their movements reflecting the movement of currents (Berger et al. 2007:1899). After maturation, movement is based on water

conditions, as well as behavioural and feeding patterns. Most mature Pacific cod are found at depths ranging from 50 to 300 m, on or near the continental shelf, but habitat depth can range from 10 to 875 m (Berger et al. 2007:1899; Johnston and Anderl 2012:25).

Although northern Pacific cod are understood to maintain this seasonal migration from deep spawning areas in the fall and winter to shallower, warmer feeding grounds in the spring and summer, this pattern is poorly understood (Johnston and Anderl 2012:25; Shimada and Kimura 1994). Additionally, it is possible that similar to their Atlantic counterparts, there are both migratory and resident Pacific cod stocks (Cunningham et al. 2009:160). A tagging study of Pacific cod focusing on the eastern Bering Sea region identified a seasonal migratory shift from feeding grounds in the summer to spawning areas in the winter (Shimada and Kimura 1994:808). The migratory pattern from this tagging study indicates that the annular cycle of Pacific cod migration begins in late September when the fish move off the Bering Sea shelf, and then in winter they aggregate in large numbers in relatively small spawning areas, the cod then disperse from these wintering areas and move further inshore for feeding, where they remain until late September when the cycle begins again (Shimada and Kimura 1994:801,808)[3].

The overall pattern of this seasonal round can generally be applied to the species, but the specific patterns for cod in the western Aleutians is unknown. Currently, there are attempts to identify a distinctive Aleutian cod stock, and Unimak Pass has been identified as a population barrier (Thomas Helser personal communication; Ormseth et al 2008:1).

[3] The authors identify one main spawning zone for the entire Bering Sea population at 157°- 170°W

As well, based on a recent study of Aleutian cod, including cod from Kiska and Amchitka Islands, there is little indication of inter-stock movement (Berger et al. 2007:1899). However, genetic testing has not yet been able to identify specific stocks throughout the Bering Sea and Aleutian Islands, which may be due to minimal inter-stock genetic variation (Gao et al. 2005:335). Genetic testing so far has demonstrated a distinction between cod of the Aleutian archipelago and the Alaskan peninsula (Ormseth et al. 2008:1). However, for commercial purposes all Pacific cod of the Bering Sea and Aleutian Islands (BSAI) are managed as one unit (Thompson and Dorn 2003:128).

Female cod reach spawning maturity at 4-5 years of age, which correlates to approximately 58 cm in size in the BSAI region (National Oceanic and Atmospheric Administration [NOAA] 2010; but see Beamish et al. 2004:375 for 2-3 years). A study of Puget Sound and Washington coast Pacific cod by Gao et al. (2005) identified that maturity was reached around 2 years of age, based on isotopic markers. Generally, spawning occurs from January to April in waters ranging in depth from 40 to 120 m, with March considered the key spawning period (Johnston and Anderl 2012:25; NOAA 2010). Eggs then sink to the ocean bottom after fertilization and hatch occurs within 8-28 days after spawning, dependent on both water temperatures and salinity, larval cod then rise to the surface where they are transported by currents, where they settle into intertidal zones as juveniles (Hurst et al. 2012; Johnston and Anderl 2012:25). However, there is evidence that juvenile (age 0) cod are not restricted to nearshore habitats, but have been captured by pelagic and demersal trawls at various depths (Hurst et al. 2012:164).

Modern Pacific cod can live up to 25 years (Berger et al. 2007:1899 from Merrell 1977 and Munk 2001; but see Johnston and Anderl 2012:25 for 17 years as maximum),

with expectations that prehistoric cod were larger and lived longer than their modern counterparts. A recent (2004) collection of Pacific cod for metal residue analysis, collected by rod and reel off Kiska Island, indicates that Kiska Island cod are currently among the smallest and youngest cod available throughout the Aleutians (Berger et al. 2007:1899).

Cod are high trophic level generalized opportunistic predators, feeding on a variety of benthic and pelagic fauna (Berger et al. 2007:1899; Urban 2012:216,218). The diet of Pacific cod in the central and western Aleutians is dominated by mackerel, and supplemented by shrimp, squid, and other fish; this is in contrast to the Pacific cod of the eastern end of the island chain, where walleye pollock dominates the diet, demonstrating the regional variability of the species (Logerwell et al. 2005:105). In a recent dietary study of Pacific cod in the Gulf of Alaska region, it was determined that diet consisted mainly of crabs (*Chionoecetes bairdi*, *Paguridae*), shrimps (*Pandalus eous* and *Crangon* spp.), and Pollock (*Theragra chalcogramma*). Pollock has also been identified as constituting up to 70% of Pacific cod diet, increasing in direct relation to fish size (Tokranov and Vinnikov 1991; Yamamura et al. 1993:46). As relatively high on the trophic level index for the North Pacific, cod are predated mostly by halibut, fur seal, and humans (Berger et al. 2007:1899).

### 3.4 Previous Work: Otolith Analyses

Otolith analyses have been a component of fisheries biology since the observation and identification of otolith annuli in 1899 (Reibish 1899 from Jackson 2007:323-324). The main goal at the time was to use otoliths to improve upon existing aging methods,

this especially occurred as a result of the identification of otolith daily growth structures in 1971 (Pannella; further extended for *Gadus morhua* by Steffensen 1980). The subsequent methodological developments and growing popularity of otolith microstructure analysis led to the development of otolith chemistry, which has now become an integral and standard component of otolith analyses (Campana 1999:263).

The analysis of the chemical composition of otoliths has been ongoing since the late 1970s (Elsdon et al. 2008:298). However, it is only since the late 1990s that otolith chemical analyses have developed to include migratory components (Elsdon et al. 2008:298), which has led to the development and refinement of techniques providing tight spatial control for sampling (e.g. microdrilling, Secondary Ion Mass Spectrometry [SIMS]). Chemical analyses developed out of a goal to reconstruct the environmental history of the fish through an understanding of the factors that influence the isotopic composition of otoliths (Campana 2005:489). The further development and refinement of micromill sampling techniques, as used in this study, has allowed for the extraction of high resolution environmental data from otoliths, and for the precise measurement of the otolith's isotopic and elemental composition (Campana 2005:489; Høie et al. 2004:1039).

Archaeological applications are directly related to this development, out of paleontological studies, focusing on otoliths as palaeoclimate proxies. The successful reconstruction of the fish's life history, through the combination of microstructural and chemical analyses, has led to successful applications identifying temperature histories, migration patterns, and stocks, as well as providing age and season of capture validation (Campana 1999:264; e,g, Patterson et al. 1993; Schwarcz et al. 1998).

Presently there are three general categories of otolith research: macrostructure analysis, microstructure analysis, and otolith microchemistry (Clemens and Noakes 2012:2). The overall goal of these three categories of research in fisheries biology and related fields is to "discriminate among fish taxa and stocks; to inform assessment models and improve understanding of population dynamics, including migration behaviours, rearing environments, and overall habitat use at particular ages" (Clemens and Noakes 2012:2). Microstructure analysis continues to be one of the main aspects of otolith research (Campana 2005:486), and is primarily used for age, growth, and stock discrimination studies. For Pacific cod, otoliths have been used exclusively for aging since the 1980s, which has substantially contributed to the development of microstructure analyses (Johnston and Anderl 2012:25). Otoliths continue to be the most widely used structure to identify stocks and discuss fish movement and migration (Elsdon and Gillanders 2002:1796). However, environmental reconstructions constitute less than 1% of total otolith studies (between 1998 and 2005) (Campana 2005:489). The main developments in this area of otolith research continue to focus on the relationship between temperature and salinity in otolith aragonite precipitation (Campana 2005:489).

### 3.4.1 Archaeological Applications

Archaeological otolith studies can also be divided into geochemical and non-geochemical categories, although there is consistently increasing overlap between the two. The main non-geochemical analyses include identifying fish species and inferring season of fish capture (e.g, Bolle et al. 2004) Geochemical investigations primarily focus on inferring the chemical composition and temperature of ambient water, validating age,

and providing season of capture estimates. Additionally, the increasing collaboration between archaeologists and fisheries biologists has also led to analyses aimed at developing comparative data sets for historic and modern species specific growth rate patterns, as well as to discuss changes in growth rates over time and patterns of exploitation (e.g. Bolle et al. 2004). Similarly to the study of incremental growth patterns of other organisms such as bivalves and corals, a main goal of archaeological otolith analyses continues to be the development of adequate and standardized methodologies for the analysis of growth band seasonality (e.g. Burchell et al. 2013a; Andrus and Crowe 2000:33). As Burchell et al. (2013b:626) demonstrate, continued methodological improvements and precise seasonal data highlight the complexity of seasonal patterns of mobility and procurement, and can contribute to the refinement of overly simplified models of seasonal behaviour.

Archaeological otoliths have most commonly been used to identify the type of fish species and infer season of capture (Andrus and Crowe 2002:292). Due to the highly species specific nature of otoliths, they are extremely useful in identifying represented species in archaeological contexts (Casteel 1976:24). Within zooarchaeological studies, otoliths are considered one of the most significant fish elements for the identification of represented species (Simons 1986:138). As well, due to the density of the calcium carbonate, fish otoliths often preserve significantly better than other fish elements, making them more available for identification (Simons 1986:138). However, the calcium carbonate can also cause otoliths to deteriorate more than other fish bone, especially in acidic conditions (Bolle et al. 2004:314; Wheeler and Jones 1989:115). Additionally, certain bony fishes have small relatively undeveloped otoliths, such as *Salmoniformes*,

and these otoliths are rarely recovered within archaeological contexts (Wheeler and Jones 1989:115). Harvesting practices also heavily influence the presence or absence of otoliths in archaeological contexts, as the fish head must be retained for the otoliths to be recovered archaeologically.

Identifying season of fish capture is a main application of archaeological otolith analysis. Site seasonality is integral to understanding subsistence patterns and resource strategies, and the analysis of otolith growth structures to determine season of capture allows for the inference of season of site occupation (Andrus and Crowe 2000:33). The non-geochemical assignation of season of capture is completed through an analysis of thin sectioned otoliths to visually identify seasonal banding (West et al. 2012:3278; e.g. Van Neer et al. 1999:120). However, it has been demonstrated that visually identifying the level of transparency or opaqueness of the otolith margin is not an accurate method to determine season of capture due to variation in deposition rates and inter reader disagreement (Bolle et al. 2004; Geffen et al. 2011:1082). Additionally, with archaeological otoliths the outer edge can be altered by the depositional environment making the visual identification of the outermost band more challenging and problematic (West et al. 2012:3278). The relatively recent addition of high resolution isotope analysis has significantly contributed to this discussion, and confirmed that visual identification of annular bands is problematic. By aligning isotope values with visible seasonal bands, seasonal patterns are more identifiable allowing for the verification of season of capture and increased interpretative confidence (Andrus et al. 2002:1509; Kastelle et al. 2012; Matta et al. 2013).

In zooarchaeological analyses of fish assemblages, there are a variety of other non-geochemical otolith analyses that can be performed. For example, otoliths from archaeological assemblages have also been used to estimate fish weight and length (Casteel 1976:26; Wheeler and Jones 1989:145). Although the algorithms to determine fish length based on otolith length are now standardized by species, archaeologically there are issues due to fossilization and post depositional processes (e.g. Reitz and Wing 2008:186-187). Archaeologically, otolith weight cannot be used as a factor in algorithms because of the impacts of fossilization and weight change from post-depositional processes (Casteel 1976:27).

Otoliths are also analyzed to investigate the dynamics of fish populations through time (Andrus and Crowe 2002:292). Otolith microstructure provides insight into patterns of fish growth rates over time, as well as the relationship between fish growth and behavioural patterns, increased predation, and exploitation (e.g. Bolle et al. 2004; Geffen et al. 2011; Van Neer et al. 1999). Growth rate analyses are closely tied to the development of industrial scale fisheries and studies do not yet extend past the historic period. To date, analyses have indicated that the impact of heavy exploitation on population size does not affect adult growth but influences juvenile growth, and have highlighted the importance of shifting temperature regimes on growth and population (Bolle et al. 2004:314 but see discussion; Geffen et al. 2011).

Although these studies have the potential to address archaeological issues, they have a more fisheries research focus, allowing for a greater emphasis on archaeological research questions in future studies. Amorosi et al. (1994) highlight the significance of increasingly combining zooarchaeological and fisheries biology research to provide new

insights into fish behaviour and exploitation in both research areas. This collaboration allows for a better comprehension of both fish harvesting patterns and the influence of harvesting on life history and behaviour (Geffen et al. 2011:1081). Additionally, further amalgamation of archeological and fisheries biology techniques will allow for further investigations of fish growth rates over time, which can be better linked to broader discussions of changing socioeconomic strategies (Bolle et al. 2004:314).

A variety of studies have attempted to further refine and establish a methodological and interpretative framework for inferring seasonality and climate from otolith growth bands and stable isotope analysis (Disspain et al. 2011; Geffen et al. 2011; Hufthammer et al. 2010; Walker and Surge 2006; West et al. 2012; Wurster and Patterson 2001). These studies contribute to a growing body of literature attempting to further establish a methodological approach that can provide adequate data resolution for archaeological material tailored to archaeological research questions. The major analytical limitations within the studies published to date lie in the availability of well-preserved samples, sample size, and arbitrary sampling units.

Interpreting otolith isotope data can also be problematic. As discussed above, there are a series of assumptions necessary for the interpretation of otolith isotope values, and although these assumptions are investigated for modern otoliths, and analytical and interpretative parameters have been established, this has not been expanded to include archaeological otoliths. For example, habitat requirements of prehistoric and historic period fish must be considered analogous to modern species. However, since otolith chemistry research has become an established component of fisheries biology, it has been

demonstrated that the basic assumptions and analyses can also be applied archaeologically (Andrus and Crowe 2002:292).

Therefore, despite the issues related to applying modern assumptions to archaeological material, the understanding of the environmental influences of otolith composition allows for the extension of, at the least, the basic assumptions of otolith microchemistry to reconstruct the past environment of the fish, which is otherwise unknown (Campana 2005:489). However, there is disagreement on the extent of the interpretative value of archaeological data. For example, assigning absolute water temperature values based on the interpretation of the stable oxygen isotope values (e.g. Andrus et al. 2002) relies on assumptions of water conditions over time.

Additionally, Campana (2005:489) points out that due to issues interpreting the complicated relationship between temperature and salinity and their effects on otolith microchemistry, environmental reconstructions have not been significantly successful for modern otolith analyses. However, due to the inability to further test this relationship or explore the assumptions of oxygen and carbon uptake in archaeological or fossilized otoliths, paleoenvironmental reconstructions are more generally utilized more than reconstructions based on modern data. If the assumptions are acknowledged and the data are considered a building block to develop a better understanding of past water conditions, fish life histories, and the relationship between these and the occupants of the archaeological site, then there is significant value in the geochemical study of archaeological otoliths. While considering these critiques, there are a series of influential studies that act as the methodological and interpretative framework for this research.

The first published attempt to use otoliths as indicators of palaeoclimate (temperature) was an extension of analytical techniques developed for other fossilized carbonate structures (Devereux 1967 in Casteel 1976:35). Devereux (1967) analyzed the $\delta^{18}O$ values for a collection of Pliocene and Miocene marine otoliths, categorizing the otoliths based on their temperature agreement with foraminifera values (Casteel 1976:35-36). As a proxy for palaeoclimate conditions, and unlike most other proxies which are immobile, otoliths provide a record representative of the fish's changing habitat. Although they provide a unique insight into various habitats and can avoid issues related to micro-environmental sensitivity, otoliths also present a challenge because of the relatively unknown behavioural characteristics of most fish species.

For studies with a palaeoclimate emphasis, otolith data is often thoroughly integrated into other paleocliamte data sets. For example, Pellegrini and Longinelli (2008:119) analyzed Canoa period (Late Pliocene to Early/Middle Pleistocene) otoliths (n=64 samples) as a component of a larger palaeoenvironmental analysis and determined variation between coastal and off-shore temperatures, as well as significant warming in water temperature over time. Ivany et al. (2000) demonstrate an overall 4°C decrease in temperature at the Eocene/Oligcene boundary at 33.75 mya based on eel otoliths (*Congridae*; *Ophidiidae*). Andrus et al. (2000) reconstructed absolute sea surface temperature from mid-Holocene catfish (*Galeichthys peruvianus*) otoliths, and identify a decrease in summer seas surface temperatures over time (ca. 3-4°C). As with other palaeoclimate studies, this otolith data is integrated with other proxies, such as lake sediments, and pollen and ice cores. As demonstrated below, archaeological studies mostly refrain from reconstructing absolute temperature values, with further emphasis on

season of capture and fish growth rates, with otolith data integrated into modern analogous data rather than palaeoclimate proxies.

Hufthammer et al. (2010) successfully demonstrate the viability of micromilling archaeological otoliths (*Gadus morhua*) to determine season of site occupation for Mesolithic coastal sites in Norway. The authors determine that the material at the outer edge of the otolith is representative of the coldest water temperatures (winter or early spring), providing an independent verification for season of site occupation (Huftammer et al. 2010:78). The aim of this study was to verify season of death based on microstructure interpretation and isotope analysis. Due to this study's emphasis on edge material and assigning season of capture, there was no attempt to establish seasonal cycles representing the fish's life history, which limits the interpretative value of the data.

Also working with Atlantic cod, Geffen et al. (2011) analyzed otoliths (n=43) from medieval sites in northern Norway. Expanding beyond identifying season of capture, the authors aimed to reconstruct temperature regimes. The authors completed elemental, isotopic, and microstructure analyses to determine temperature regimes, growth, and stock determination/geographic source (Geffen et al. 2011:1082). Analytically, the major limitation is that the analysis is restricted to the fish's second year of life (Geffen et al. 2011:1083).

For Pacific cod, West et al. (2011, 2012) also apply a micromilling technique to determine relative variation in water temperature throughout a 500 year occupation on Kodiak Island in the Gulf of Alaska. As this study primarily focuses on average $\delta^{18}O$ values, sampling was completed by establishing transects through the entire otolith, so that values represent both summer and winter bands, preventing further seasonal

discrimination (West et al. 2012:3280) (n=15, fish aged 3-6). West et al.'s (2012) analysis provides a significant comparative data set for this study as this represents the only comparable archaeological data for the Pacific and provides the methodological foundation for this thesis.

Walker and Surge (2006) looked at a collection archaeological Hardhead catfish (*Ariopsis felis*) otoliths as part of a larger analysis of Late Holocene human-climate interaction in southwest Florida. They compared data between shell and otolith aragonite, and argue that the comparison of two taxa significantly aids in the analysis and interpretation of $\delta^{18}O$. When comparing their data to the occupation periods of the site they were able to identify two distinct climatic periods within their samples that correspond to changes in site occupation, which they hypothesize is climate based (Walker and Surge 2006:3).

This study is further refined by Wang et al. (2011), with a focus on identifying the seasonal summer characteristics for a specific time period (AD 500-800). Their analysis is based on identifying contemporaneous shell-otolith pairs with tight chronological control, which greatly increases interpretative and analytical confidence and expands the applicability of the results.

Wurster and Patterson (2001) analyzed a collection of freshwater fish otoliths (n=14, 232 samples per otolith) recovered from a rockshelter archaeological site in Tennessee to provide high resolution climatic data from the mid-Holocene onwards with a focus on identifying maximum summer temperatures (Wurster and Patterson 2001:82-83). They successfully aligned the $\delta^{18}O$ values with visible annuli to determine the represented years or age of the otolith (Wurster and Patterson 2001:83). However, they

only analyzed the samples that they determined represented seasonal minima and maxima (2001:83)

Other research include Disspain et al.'s (2011) analysis of archaeological fish otoliths from southern Australia to reconstruct environmental conditions experienced by the fish through the late Holocene. The authors conclude that the majority of fish were captured during the warm season in fresh water environments at sexual maturity (Disspain et al. 2011:1842).

Andrus and Crowe (2002) address the issues associated with the archaeological assumption that otoliths are unaltered from capture to analysis through an experimental assessment of the impacts of various forms of cooking on otolith aragonite geochemistry. They demonstrated that burning causes recrystallization of the otolith aragonite into calcite, causing subsequent alterations to the otoliths isotope chemistry. The results of their analysis indicate that stable isotope analysis can only be considered accurate for unburned otoliths (Andrus and Crowe 2002:291).

The studies discussed above serve as the methodological and interpretative building blocks that inform this research project. Although this research expands on and contributes to the development of this technique, the limited sample size, although comparable to other studies, leads to similar limitations as previous studies. Additional works could eliminate this as the excellent preservation of otoliths from Kiska Island potentially allows for a larger sample size. Further analyses would also benefit from the addition of shell isotope data, similar to Wang et al. (2011). However, this study represents a foundational attempt to isolate isotope values from discrete annuli and to align these with otolith structural composition.

# Chapter 4: Methods and Materials

This chapter outlines the methods and materials involved in the recovery and analysis of otoliths (n =114) from two seasons of test excavations on Kiska Island. Of the total 114 otoliths, seven were sampled for stable isotope analysis totalling 146 subsamples (see Table 5.1). A selection of modern and historic Atlantic cod otoliths (n=59) were also analyzed to better develop the methodological and interpretative framework, and are included in this methodological discussion. Of the total 59 Atlantic cod otoliths, eight were sampled for stable isotope analysis totalling 91 subsamples. The main stages of analysis addressed in this chapter are: 1) the morphological examination to determine nearest identifiable taxa, side of the otolith, and otolith attributes, 2) the age of the fish and identification of annular/seasonal banding, and 3) the isotopic analysis to interpret season of capture, identify relative cycles of seasonal variation, and infer ambient water temperature based on $\delta^{18}O$ values.

## 4.1. Field Methods

This project consists of the analysis of otoliths recovered from two middens on Kiska Island: Gertrude Cove (KIS-010) and Witchcraft Point (KIS-005) (Figures 2.3, 4.1, 4.2, 4.3). Permit requests were granted for test excavations due to evidence of looting at Gertrude Cove and significant erosion at Witchcraft Point. The field work was completed in collaboration with the United States Fish and Wildlife Services (USFWS) and in consultation with USFWS Regional Archaeologists. USFWS issued the permit for Witchcraft Point to collaborators V. Lech, V. Grimes, I. Jones, and C. Hutchings. The midden at Gertrude Cove was recently (2011) conveyed to the Aleut Corporation (TAC)

as a registered burial site. TAC issued the permit for Gertrude Cove to project director Jones and collaborator Lech.

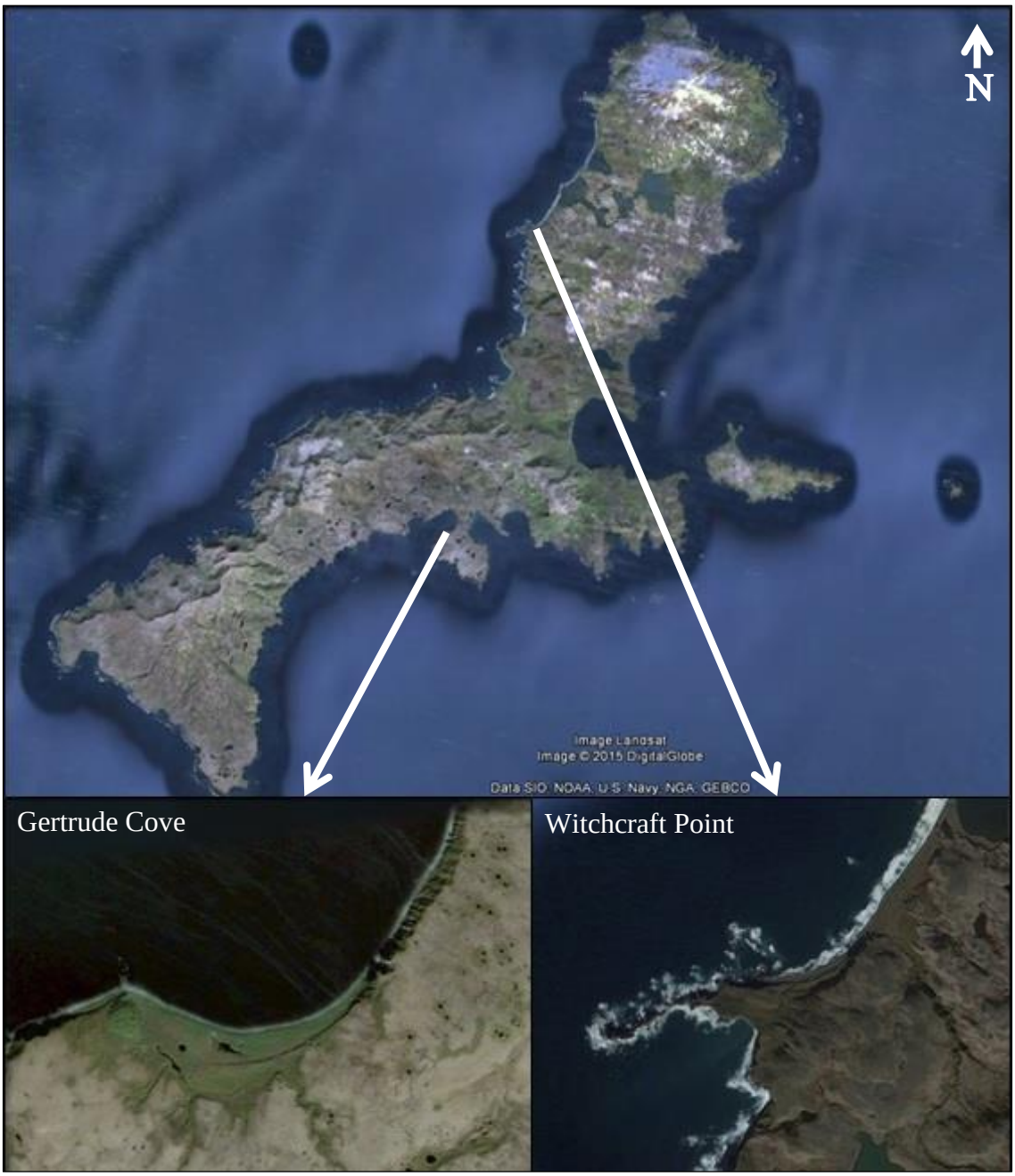


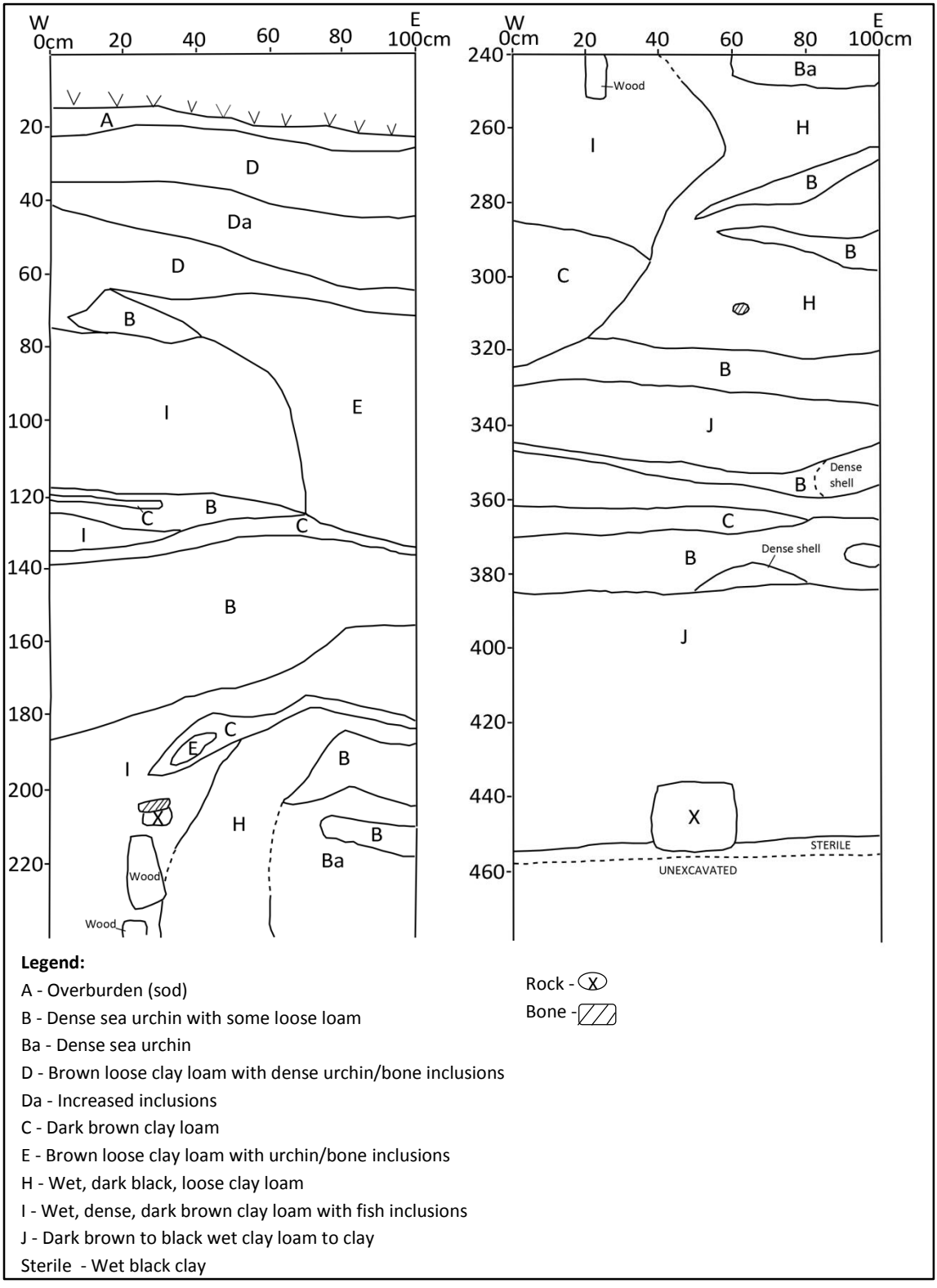

**Figure 4.1: Location map of Kiska Island inset of Gertrude Cove and Witchcraft Point (modified from Google Earth 2015).**

**Figure 4.2: Witchcraft Point with eroding face on left and excavation in progress on right. Photo by author (left) and courtesy of C. Hutchings (right).**

**Figure 4.3: Gertrude Cove with midden face on left and excavation in progress on right.**

One metre square units were excavated by trowel, with a total of five units excavated at Witchcraft Point and four units at Gertrude Cove. The units were excavated by 10-20 cm arbitrary levels, and dirt was screened through ¼" mesh. All archaeological material was collected at Witchcraft Point, including all artifacts and faunal material. Faunal material was divided by class and stored in separate collection bags by each arbitrary level. Artifacts were stored in separate bags, also by arbitrary level. A fish sampling strategy was employed for secondary units at Gertrude Cove to facilitate the excavation to sterile soil, with all archeological material collected from the primary unit.

The fish sampling strategy consisted of collecting and retaining a 1L bag of soil for each level to preserve a sample of fish remains from each arbitrary level; the remainder of the fish remains were not collected. Wall profiles were completed for all units, and plan views and photographs were used to record each level. Charcoal samples were collected in situ from each arbitrary level and have been correlated with cultural layers based on wall profiles (see Figure 4.4 for profile example).




**Legend:**

A - Overburden (sod)

B - Dense sea urchin with some loose loam

Ba - Dense sea urchin

D - Brown loose clay loam with dense urchin/bone inclusions

Da - Increased inclusions

C - Dark brown clay loam

E - Brown loose clay loam with urchin/bone inclusions

H - Wet, dark black, loose clay loam

I - Wet, dense, dark brown clay loam with fish inclusions

J - Dark brown to black wet clay loam to clay

Sterile - Wet black clay

Rock - (X)

Bone - ////

**Figure 4.4 North wall profile of Unit 2 (primary unit).**

For a seven week period, from June to July 2010, test excavations were completed at Witchcraft Point. The crew of three (A. Bond, C. Hutchings, I.L. Jones) excavated a total of six units, four of which were excavated to sterile soil at approximately three metres depth below datum (dbd), with the two remaining units reaching depths of approximately two metres below datum. Time constraints prevented further excavation to subsoil, as well as the excavation of the remaining three units of the nine unit grid. Overall, the units represent a limited portion of the overall midden and the location was selected based on the highest threat of erosion (Lech and Hutchings 2010).

Excavations were conducted at Gertrude Cove over an eleven week period, from May to August of 2011. A field crew of two (D. Pirie-Hay and C. Young-Boyle, with the addition of V. Lech for the first two weeks of the field season) excavated a total of four units; of these, one unit (Unit 2) extended to subsoil at 4.5 metres dbd. Units 3 and 4, ranging from 1.5 to 3.5 metres dbd, were opened as secondary units to allow for the continuation of Unit 2 to sterile soil. Unit 1 was originally intended as the primary unit, but was abandoned after human remains were uncovered at 90cm dbd. The unit was sealed and backfilled in consultation with Debbie Corbett of USFWS and Melvin Smith of TAC. All material was collected from the primary unit, and a fish sampling strategy was employed for secondary units to maximize the potential of reaching sterile soil. Soil samples were collected from each identified cultural layer.

The analysis of the material recovered from Kiska Island is ongoing. All artifacts from Gertrude Cove have been analyzed and returned to Debbie Corbett, at the request of TAC, and a preliminary report has been submitted to USFWS (Lech et al. 2012). A preliminary analysis has been completed for Witchcraft Point material and a preliminary

report has been completed (Lech and Hutchings 2010). A complete zooarchaeological analysis of the recovered fauna is still required.

### 4.2 Otolith Analysis: Morphological

Otoliths were sided and identified using a combination of reference collections. Atlantic otoliths were identified based on a modern reference collection supplied by SeaWatch students training at the Marine Institute, and in reference to Campana's (2004) photographic atlas of Atlantic fish otoliths. Additionally, students working on otoliths at the Marine Institute's Centre for Fisheries Ecosystem Research (CFER) were consulted (Victoria Neville, personal communication 2012). Pacific otoliths were primarily identified based on Morrow's (1979) key of Bering Sea otoliths (see West et al. 2011), Harvey et al.'s (2000) images of eastern North Pacific otoliths, and Frost's (1981) descriptive key. Further positive identification was based on reference otoliths collected in the field (Gertrude Cove 2011; *Gadus macrocephalus* n=1). This reference collection consisted of a Pacific cod donated by USFWS staff during the Kiska Island field season. The cod was placed in the interidal zone for the duration of the field season to facilitate the removal of all soft tissues. At the end of the field season the cod was cleaned with boiling water and sorted by marine biologists on site (D. Pirie-Hay) and returned to the Archaeological Sciences laboratory at Memorial University as a complete modern Pacific cod reference. In addition, otoliths selected for thin sectioning were confirmed to species by aging specialists, as discussed in Section 4.2.1.

Otoliths were identified to nearest taxonomic level and catalogued with associated stratigraphic data and measurements. All measurements (maximum width, length and

thickness) were taken with digital calipers to the nearest mm. Otoliths selected for isotopic analysis were weighed to the nearest milligram. The otolith catalogue is provided as Appendix A.

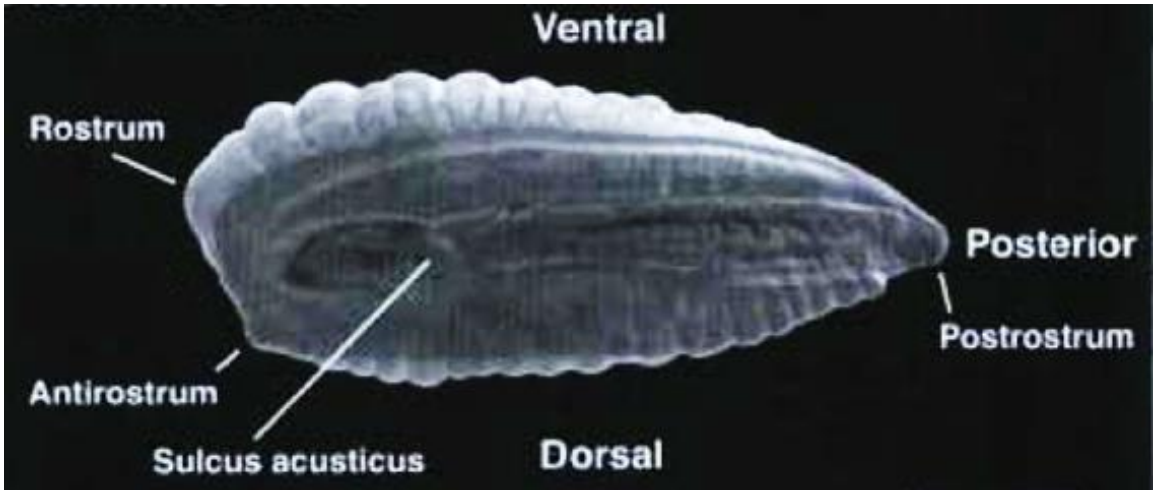



**Figure 4.5: Otolith morphological features referred to in text, proximal surface (modified from Campana 2004:4).**

Photographs were taken of all otoliths, either individually or in groups. Images were taken of medial/proximal (sulcus) surfaces oriented with the rostrum and antirostrum up (see Figure 4.5 for morphological features, no scale provided in original image). Images of the distal surface were taken when required and for otoliths selected for geochemical analysis. Additionally, thin section images were also used for microstructural analysis. Atlantic cod thin section images were taken at the Centre for Fisheries Ecosystems Research (CFER) Otolith Lab using an Olympus SZX16 stereomicroscope and Pacific cod thin sections were imaged by the National Oceanic and Atmospheric Administration's (NOAA) Age and Growth program using a camera mounted dissecting microscope. As well, a further description of each otolith selected for geochemical analysis was completed; including the identification of shape, overall form,

sulcus description, and a description of any other distinguishing characteristics (see Disspain et al. 2011:1844).

### 4.2.1 Aging and Seasonality

"It is not complete exaggeration to say that the best (most reliable) specimen of Pacific cod otoliths is worse than the worst specimen…from the Atlantic." (Ketchen 1970)

An age estimate was obtained for all otoliths selected for geochemical analysis (n=15). This was accomplished by distinguishing between seasonal annuli to estimate fish age and season of capture. Aging for Pacific cod otoliths was completed by professional agers at NOAA's Age and Growth Program (Seattle, USA), primarily Johnston and Kastelle, with the assistance of Helser (personal communication 2013). Atlantic cod otoliths were aged in consultation with an otolith analyst at CFER (Victoria Neville, personal communication 2012). The methodology used for aging is outlined by Campana (1992; also see Campana and Neilson 1985) for Atlantic species and Matta and Kimura (2012) for Pacific species, and are the current and most accurate aging techniques in use for commercial groundfish age estimation and fisheries research.

The annular marks in *Gadidae* fishes are represented by a pair of opaque and translucent bands that reflect one year of fish growth (Matta and Goetz 2012:5). The critical underlying assumption in otolith aging is that the annular bands are reflections of yearly growth and not of other environmental or behavioural factors (Matta and Goetz 2012:6). Pacific cod otoliths are infamously difficult to age with a low aging accuracy, and although we assume the bands are representative of yearly deposition, there are a variety of influential factors that could lead to errors in age estimation (Johnston and

Anderl 2012; Ketchen 1970; Matta and Goetz 2012:6-7). As a result, age validation is a major component of otolith research and the addition of stable isotope analysis is one of several age validation methods that are constantly being reviewed and refined in an attempt to improve aging methods, especially for commercially significant groundfish species. To address these issues, this study collaborated with laboratories and personnel with training and experience in cod age and growth determination.

Sub-annual variations and capture estimates were determined visually, as described above, as well as geochemically. Initial determinations were based on the visual identification of the presence/absence of winter and summer banding through thin section images. These annular identifications were further confirmed through the isotopic analysis, based on the relative seasonal signatures of winter and summer annuli. To confirm season of capture observations, the $\delta^{18}O$ values of the otolith's outer edge (deposited at time of capture) was compared against individual and mean winter and summer $\delta^{18}O$ values for each otolith, with the attempt to provide an independent means of verifying season of capture.

Otolith aging and interpreting otolith structure is a complex procedure and generally involves multiple independent age readers and the inclusion of calibration exercises to increase precision (Bolle et al. 2004:317). The potential for error in this study is further compounded due to the overall difficulty in applying these methods to archaeological otoliths.

### 4.3 Otolith Analysis: Geochemical

Otoliths accrete mineral layers precipitated from the inner ear fluid as the fish grows, and are metabolically inert after absorption. As a result, otoliths act as natural tags representing the water chemistry the fish encountered throughout its life (Hanson et al. 2010:2491; Elsdon et al. 2008:298). The geochemical analysis for this study was completed for a selection of otoliths (n=15) based on stratigraphic association, preservation, radiocarbon dates, and completeness. Otoliths retaining their outer edges were preferred for analysis because of the retention of the most recent seasonal data. Additional filtering was based on otolith species (cod) and size. The otoliths recovered from Kiska Island, especially those from Gertrude Cove, are in excellent condition for archaeological otoliths. A sample size of 15 otoliths (7 Pacific, 8 Atlantic) was determined to be adequate based on the sample sizes of previous archaeological otolith analyses (Geffen et al. 2011; Hufthammer et al 2010; Walker and Surge 2006; West et al. 2012), and was necessary due to time, budgetary, and analytical constraints.

The method employed for the collection and analysis of calcium carbonate powder, as outlined below, is the method currently in use for isotopic studies of fish movement and migration at the Otolith Laboratory at CFER (Campana 1992) in combination with age and growth studies by NOAA (Helser and McKay 2013; Kastelle et al. 2012; Thomas Helser, Craig Kastelle, Chris Johnston personal communication 2012-2013). Our application of this method differs from other studies of archaeological otoliths by our attempt to identify and micromill individual annuli within each otolith, thus providing a tighter temporal resolution than past studies that sampled across multiple annuli within an otolith (e.g. West et al. 2012). This application demonstrates an

amalgamation of established fisheries, palaeoclimate, and zooarchaeological methods; as well, this is an improvement upon previous archaeological otolith studies due to the increased temporal resolution, control, and decreased contamination between annuli. The results better outline temporally specific seasonal variations to further identify change/stability over time, and provide a more accurate and independent means of identifying season of capture.

### 4.3.1 Sample Preparation

All otoliths selected for thin sectioning were decontaminated. Otoliths were placed in a clean vial filled with deionized water (17.5 MΩ, Millipore Canada) and sonicated for five minutes to loosen attached particles. Any otoliths requiring further removal of loose dirt and other material were gently cleaned with an acid-washed toothbrush and deionized water. All otoliths were then triple rinsed with deionized water, placed in the sonicfier for an additional three minutes, triple rinsed again, and placed in a fume hood to air dry for 18-24 hours. After decontamination and drying, otoliths were weighed again.

For the embedding process, silicon molds were used. Before embedding, the molds were covered with a releasing agent (Frekote, Henkel, Canada), and labels were prepared for each otolith. Epoxy resin (Buehler Epothin Resin, Illinois, USA) was mixed with epoxy hardener (Buehler epothin hardener, Illinois, USA) at a 5:2 ratio. The material was mixed with a stir stick in a plastic cup for two to three minutes. The mixed embedding material was then sonicated for five minutes.

Each otolith was then placed in a mold (25.65 $cm^3$, Wilton Industries, Illinois, USA) medial side up, with the corresponding label. Epoxy was poured into the mold with a small space left at the top. Bubbles were removed from the surface with a toothpick, plastic forceps, and a pipette. Otoliths were then quickly turned distal side up, with the anterior tips facing the same side and the remainder of the mold was filled with epoxy. The mold was then placed in the fume hood to dry for 10-24 hours. The embedded otoliths were then removed from the silicon mold and left to dry for 72 hours before sectioning.

Sectioning was completed on a Buehler IsoMet low speed diamond blade saw (Illinois, USA) with 6 mm spacers and 3 mm wafering blades at CFER's Otolith Lab, with the assistance of CFER and the aid of otolith technician Victoria Neville (Figure 4.6). The otolith core was identified before sectioning. Blades and spacers were placed on the saw and the bath was filled with deionized water. The otolith molds were positioned, one at a time, between the clamps on the saw. The otoliths were placed with the flattest mold surface (medial surface) facing the blade and the anterior tip of the otolith facing outwards. Before sawing, it was verified that the core of the otolith was oriented directly over the saw. The saw was then turned on and thin sections were completed

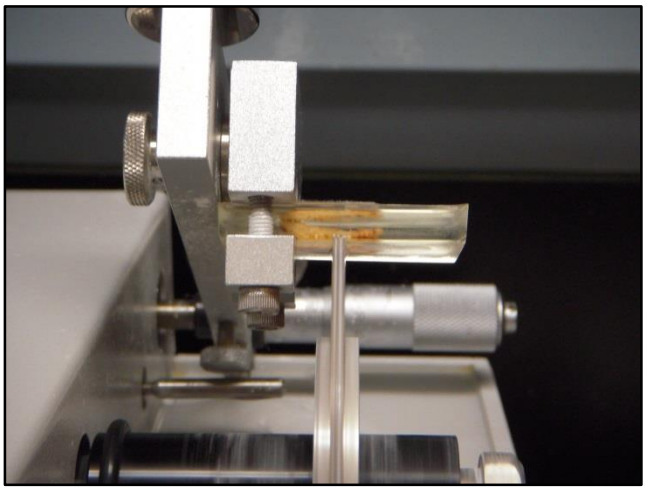


**Figure 4.6: Otolith sectioning.**

All thin sections were immediately labelled. The sections were then positioned in a petri dish with ethanol and images were taken. Aging was initially completed at this point and images were taken for all sectioned otoliths. Images were then digitally edited to improve clarity for external age verification and publication.

All Pacific cod otoliths were decontaminated and embedded following the process outlined above, and one otolith was thin sectioned as above. All otoliths were then submitted to NOAA's Age and Growth program. At the Age and Growth Program's facilities (NOAA, Seattle, USA), two 0.2mm thin sections were obtained from each otolith using a Buehler Isomet 5000 Linear Precision diamond blade saw (Illinois, USA). These were then affixed to slides using Loctite adhesive resin, and the samples were polished with a Hillquist thin section grinder (Colorado, USA) for optimum clarity. Image analysis was then completed by a series of professional agers on site. All material, thin sections, and digital images, were returned to the author and V. Grimes for analysis and curation.

### 4.3.2. Sample Collection

A total of 15 otoliths were subsampled by micromilling, as outlined above, resulting in the collection of 197 samples for isotope analysis to determine carbon and oxygen ratios. Samples were micromilled at Memorial University's CREAIT Microanalysis facility with a New Wave Research ESI Micromill (California, USA) equipped with a 0.3 mm drill bit, as shown in Figure 4.7.

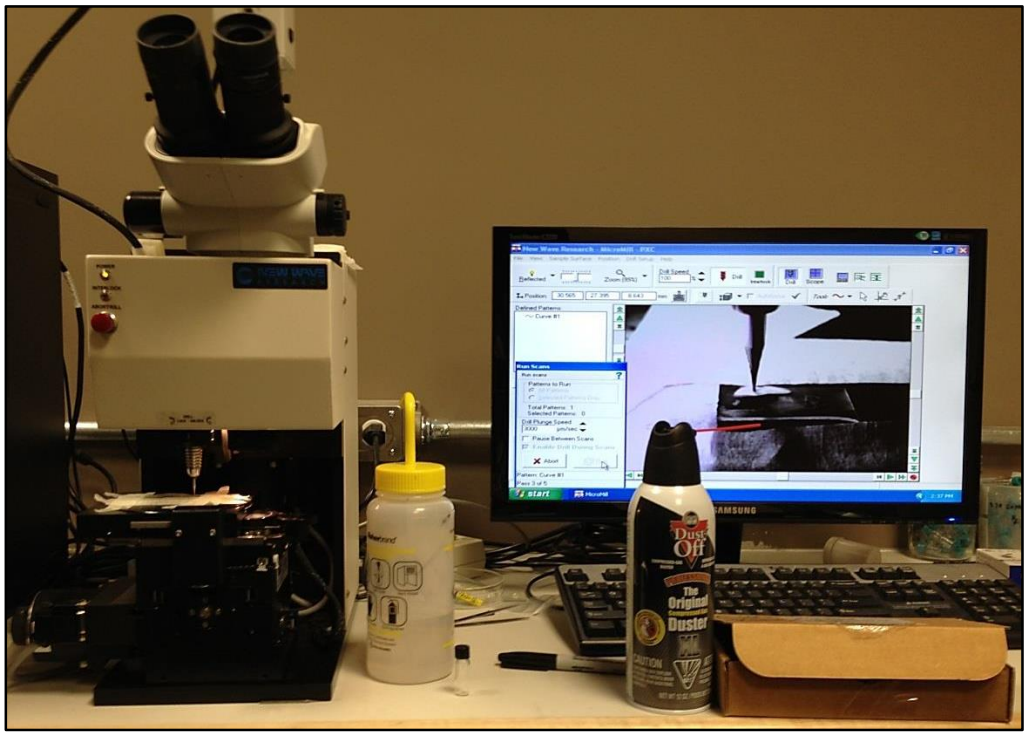



**Figure 4.7: Otolith micromilling process and equipment.**

Otolith thin sections were affixed to microscope slides with adhesive and fastened to the plate of the drill, as visible in Figure 4.7. The thin section surface selected for drilling was based on clarity and visibility of the annuli. The annuli, as visible through the micromill microscope, were constantly checked against the original images and age

estimates to ensure compatibility and accuracy. The drill bit and otolith surface were cleaned between each use with ethanol and dried with compressed air. Each otolith annuli was micromilled to collect discrete samples from the core to the margin of the otolith. Additional edge material was obtained from an ideal edge location, which was determined in consultation with otolith age readers. Material was collected by shaving outwards from the core, and additional edge material was collected by drilling a channel into the resin adjacent to the otolith margin, to avoid contamination and catch the powder, before shaving off the outer margin (Craig Kastelle personal communication 2013). Samples from each otolith were collected from the same reading axis and additional edge material was collected from the optimum edge location.

Powder was collected from each annuli and placed into a glass vial or tin elemental analysis capsule (Elemental Microanalysis Ltd, UK). Atlantic cod samples were placed into decontaminated glass vials (following Memorial University's Stable Isotope Lab protocol) and then transferred into laboratory vials at Memorial University's Stable Isotope Lab (A.Pye). Pacific cod samples were either placed directly into sample holders specifically designed for otolith carbonate powder (J. McKay, CEOAS, Oregon, USA; Figure 4.8).


**Figure 4.8: Carbonate sample holder used for Pacific cod otolith samples.**

No weights were obtained for Atlantic cod samples before submission for isotope analysis because of sample size issues, risk of material loss, and static. All carbonate samples from six of the seven Pacific cod otoliths were weighed prior to shipping to Oregon State University's College of Earth Oceanic and Atmospheric Sciences (CEOAS) Stable Isotope Lab for analysis (J. McKay). The majority of samples were weighed at Memorial University's Stable Isotope Lab on a Mettler Toledo A121 Comparator (Mississauga, Canada) and 20 samples were weighed in CREAIT's microanalysis facility on a Mettler Toledo UMX2 Dual-Range Microbalance (Mississauga, Canada).

### 4.3.3 Mineral Structure Analysis (FTIR)

Calcium carbonate crystalizes as different polymorphs, and otoliths can exist naturally as aragonite and vaterite; saggital otoliths most commonly crystalize as aragonite (Campana 2004:3; West et al. 2012:3280). However, aragonite is less stable

than calcite and the depositional environment has the potential to alter the aragonitic structure of the otolith, which usually occurs through recrystallization, creating a more calcitic material and impacting the oxygen isotope values (Campana 1999:265; Weiner 2010:7). As a result, the identification of the mineral structure of the otolith is integral to interpreting the isotopic data; for example, vaterite does not precipitate in equilibrium with ambient water (Campana 1999:265).

Different methods are available to identify otolith mineral structure, one of which is Fourier Transform Infrared Spectroscopy (FTIR), but X-Ray Diffraction (XRD) is also commonly used (see West et al. 2012:3280 and Hanson et al. 2010:2493). For this study, FTIR was used to identify the material and structure of a selection of otoliths (n=15) to determine their suitability for isotopic analysis and to assist in interpretation (Regev et al. 2010:3022; West et al. 2012:3280). FTIR is an absorption technique that measures the interaction between radiation and the sample material in the infrared (IR) spectrum, and produces measurements as a series of peaks representing wavenumbers ($cm^{-1}$) and absorbency (Weiner 2010:1). The series of peak maximums are material specific, allowing for identification based on these wavenumbers. There are three characteristic signatures (IR absorption peaks) for calcite, representing alterations in the biogenic calcite after deposition, as the calcium carbonate further crystalizes into calcite (Regev et al. 2010:3023).

All otoliths subjected to isotope analysis (n=15) were also analyzed by FTIR, totalling 40 samples. Otoliths were milled for approximately 100 µm of powder at a location not required for isotope analysis. Samples were selected from various locations, ranging from the core to the edge of the otolith to determine inter and intra otolith

variability. The calcium carbonate powder was analyzed by the author at Memorial University's Physics and Physical Oceanography Department under the supervision of Dr. K Poduska and B. Xu (of the Poduska Research Group, Experimental Materials Physics and Chemistry, Memorial University). Otolith calcium carbonate powder was stored in tin elemental analysis capsules (Elemental Microanalysis Ltd, UK) and each sample was analyzed separately. The calcium carbonate for each sample was mixed with potassium bromide (KBr) powder using an agate mortar and pestle and ground to produce a fine, visually homogenous powder. The powder was then transferred to a dye and pressed into a transparent 7 mm diameter pellet using a hand press and placed into the instrument beam. To ensure reproducibility a selection of samples were ground, pressured, and measured twice. Infrared spectra were obtained using a benchtop Bruker Alpha FTIR Spectrometer (Massachusetts, USA) and read using OPUS 7.0 software (California, USA). The obtained spectra were compared on site and with the assistance of Poduska and Xu against known peak ratios of calcite and aragonite to determine the mineral structure of each sample. Although the samples were measured by the author the interpretation of infrared spectra is a complicated procedure requiring extensive experience and knowledge of peak ratios, and the author relied heavily on Poduska and Xu to assist with final interpretation. All results are presented as series' of IR peaks or spectra (absorption and wavenumber $cm^{-1}$ratios) compared to known calcite and aragonite IR spectra (see Figure 5.7 for a sample of results).

### 4.3.4 Stable Isotope Analysis ($\delta^{18}O$, $\delta^{13}C$)

Otoliths, as biogenic calcium carbonate structures, incorporate oxygen isotope ratios from the surrounding or ambient water (Campana 1999:275; Elsdon et al 2008:298). The stable oxygen isotope values ($\delta^{18}O$) of otoliths are at a physiochemical equilibrium with the ambient water (Campana 1999:275, 287; Hanson et al. 2010:2491; Hufthammer et al. 2010:79; Pellegrini and Longinelli 2008:123; Thorrold et al. 1997). As a result, otolith oxygen isotope values act as proxies for ambient water temperatures or chemical composition. Isotopic enrichment or depletion within otoliths is regulated by predictable physical factors. This allows for the assumption that changes identified in the isotopic composition of the carbonate reflect changes within the ambient water (as opposed to metabolic or other factors) (Camapana 1999:275).

It has been demonstrated that fractionation of oxygen isotopes, unlike carbon, are dependent on temperature (not fish growth or otolith precipitation) so that water temperature can be reconstructed within 1°C (Thorrold et al. 1997:2909; 0.3°C according to Høie et al. 2004:1042). The relationship between oxygen isotope values of otolith aragonite and ambient water temperature is similar to that of inorganic aragonite, indicating that otoliths act as accurate (paleo) thermometers (Campana 1999:268; West et al. 2012:3279). Therefore, temperature can be accurately reconstructed from otolith oxygen isotope ratios if the isotopic composition of the water is known (Campana 1999:276; Hanson et al. 2010:2491; Thorrold et al. 1997). As temperature decreases, the fractionation of $^{18}O$ into the otolith increases in relation to $^{16}O$; therefore, as water temperature decreases, $\delta^{18}O$ increases (Hanson et al. 2010:2494; Jones and Campana 2009:1503).

When applying this to palaeoclimate studies, we are unable to accurately estimate water temperature because the isotopic signature of the water is unknown. Fortunately, this eliminates the assumptions required for the calculation of actual temperature values (Hufthammer et al. 2010:83), and minimizes the need for fractionation equations designed to take into account variables related to geography, temperature, and salinity (Hanson et al. 2010:2496). For palaeoclimate applications, it is the cycle of variation in $\delta^{18}O$ values that demonstrates seasonal changes and allows for the inference of water composition (Hufthammer et al. 2010:75). The geochemical analysis of archaeological otoliths allows for the identification of relative changes in water chemistry and temperature though time, providing accurate, independent, and temporally specific palaeoclimate data (e.g. Hufthammer et al. 2010; Geffen et al. 2011; Walker and Surge 2006).

Isotope samples for this study were processed at two different laboratory facilities. All samples (n=79) from Atlantic cod otoliths were analyzed at the Stable Isotope Lab, Earth Resources Research and Analysis Facility (TERRA), Department of Earth Sciences at Memorial University using the ThermoElectron DeltaVPlus Gas Source Isotope Ratio Mass Spectrometer coupled to a ThermoElectron Gas Bench II (Massachusetts, USA) . Values are calibrated to NBS-19 ($CaCO_3$; -2.20‰ for $\delta^{18}O$) and an internal standard ($CaCO_3$; -13.40±0.412‰ for $\delta^{18}O$). For an average run of 52 samples, 18 standards are run (NBS 19). The method employed by TERRA includes the weighing of samples into glass vials; the vials are then heated in a block (50°C), flushed with helium, and injected with phosphoric acid. The gases then pass through tubing for water removal and are separated before entering the isotope ratio mass spectrometer (Memorial University

2015). A total of 4 modern and 4 archaeological otoliths were analyzed. A minimum of 50 µm of powder was collected from each annuli for analysis.

Pacific otolith samples, totalling 138 samples from seven otoliths, were processed at the Stable Isotope Lab, College of Earth, Ocean and Atmospheric Sciences (CEOAS) at Oregon State University on a Kiel III preparation device connected to a Thermo-Finnigan MAT 252 isotope ratio mass spectrometer (Massachusetts, USA) with precision of ±0.05 ‰. Values are corrected based on an internal lab calcite standard (Wiley; -7.20‰ for $\delta^{18}O$) and checked against NBS-19 (-2.20‰ for $\delta^{18}O$). Samples are reacted with orthosphoric acid at 70°C for 5 minutes, after freezing $CO_2$ and $H_20$ gases and the removal of non-condensable gases, the $CO_2$ is transferred to the Mat 252 by a capillary and analyzed by dual inlet mass spectrometry (CEOAS 2015).

All $\delta^{18}O_{otolith}$ are measured in relation to the international scale VPDB (Vienna Pee Dee Belemnite) and reported in per mil (‰) values. The resulting $\delta^{18}O_{otolith}$ values provide the basis for the methodological, climatic, seasonal, and fish harvesting discussions in the following chapters. The Atlantic cod and Pacific cod datasets are not directly compared in this thesis due to the difference in species and the Pacific cod focus of the thesis.

## Chapter 5: Results

This chapter presents the results of the otolith analysis, which includes a study of the morphology, mineral structure and stable isotope ($\delta^{18}O$, $\delta^{13}C$) values of the samples for the purpose of obtaining usable, representative potential seasonal signals. A total of 173 otoliths were analyzed, and of these 15 were thin sectioned and sampled for stable isotope analysis, resulting in the collection of 237 samples, each consisting of 50 to 100 µg of calcium carbonate powder for isotope (n=197) and mineral structure analysis (n=40) (Table 5.1). This chapter focuses on the $\delta^{18}O$ values of seven Pacific cod otoliths to provide seasonal and climatic data to contribute to site interpretation and to discuss the development and efficacy of this method for archaeological otoliths. An additional eight Atlantic cod otoliths (four modern, four archaeological) were sampled at the beginning of this project to develop the methodological approach for this study, and the results are also presented here.

**Table 5.1 Total otoliths and subsamples by sampling procedure and otolith type**

| Otolith Type | Otolith Total | Otoliths Sampled | Subsample Total ($\delta^{13}C$, $\delta^{18}O$) | Subsample Total (FTIR) |
|---|---|---|---|---|
| Atlantic cod modern | 23 | 4 | 39 | 2 |
| Atlantic cod archaeological | 36 | 4 | 40 | 10 |
| Pacific cod archaeological | 114 | 7 | 118 | 28 |
| **Total** | **173** | **15** | **197** | **40** |

### 5.1. Pacific Cod Morphological and Microstructure Analysis Results

In total 114 otoliths were recovered from the 2010 and 2011 excavations on Kiska Island. Overall, the collection size is robust and the otoliths are in good to excellent condition for an archaeological assemblage. Otoliths recovered from Witchcraft Point

display poorer preservation and increased fragmentation compared to the otoliths from Gertrude Cove. Soil samples analyzed from Gertrude Cove indicate the soil is slightly acidic, ranging in pH from 5.5 to 6 (Allen et al. 2011), and although samples have yet to be analyzed for Witchcraft Point the condition of the otoliths suggest a more acidic environment. Table 5.2 below demonstrates the total otolith count by level for both sites.

**Table 5.2 Total otoliths by site and level**

| Site | Level | N |
|---|---|---|
| Gertrude | 2 | 4 |
| | 4 | 10 |
| | 5 | 3 |
| | 7 | 1 |
| | 9 | 2 |
| | 10 | 8 |
| | 12 | 2 |
| | 13 | 2 |
| | 15 | 1 |
| | 26 | 6 |
| | Subtotal | 39 |
| Witchcraft | surface | 2 |
| | 1 | 3 |
| | 3 | 4 |
| | 4 | 7 |
| | 5 | 9 |
| | 6 | 17 |
| | 7 | 7 |
| | 8 | 24 |
| | 9 | 2 |
| | Subtotal | 75 |
| Total | | 114 |

Well preserved otoliths from Gertrude Cove (see Figure 5.1) retain morphological features such as the antirostrum, rostrum, and sulcus, and possess defined marginal lobulations and a preserved outer margin with minimal flaking (see Figure 4.5 for otolith

morphological features). Deterioration and fragmentation manifests in various ways, including: hardening, discolouration, flaking, and/or a soft, breakable, chalky texture. Generally, otoliths from Witchcraft Point exhibit deterioration through loss of the outer surfaces, marginal breakage, and a fragile flaky or chalky interior, as can be seen in Figure 5.2. The chalky texture can be a result of burning, which is most probable when it is accompanied by a hardened, blackened exterior (Andrus and Crowe 2002:296; see Figure 5.1 bottom right otolith). Burning is further addressed in section 5.3; however, FTIR samples were only taken of otoliths selected for geochemical analysis. Further analyses would benefit from conducting a structural analysis of chalky and hardened otoliths to discuss changes in mineral composition related to burning.


**Figure 5.1: Selection of complete Gertrude Cove otoliths.**

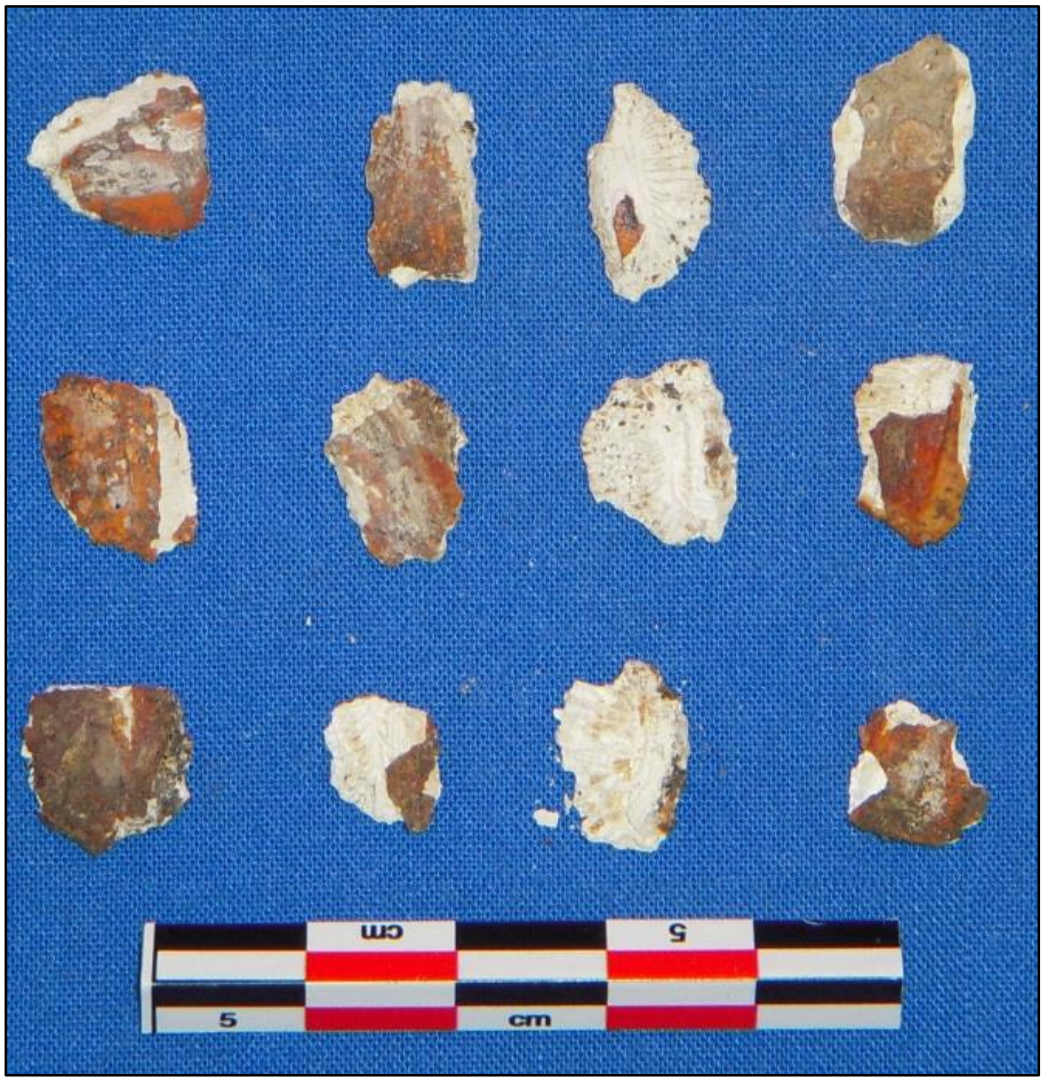



**Figure 5.2: Sample of fragmented Witchcraft Point otoliths.**

Of the total 114 otoliths recovered from the test units, 68 can be identified to family *Gadidae*, and of these 27 (24% of total assemblage) can be positively identified as *Gadus macrocphalus* (presented in Table 5.3). Other potential for identified species includes: *Eleginus gracilis* (Saffron cod), *Microgadus proximus* (Pacific tomcod), and *Theragra chalcograma* (Walleye pollock). Due to a limited reference collection, conservative identification methods, and fragmentation and deterioration, the remaining

*Gadidae* otoliths were not positively identified to species. Further work with a reference collection of *Gadidae* otoliths would improve identification.

Of the 39 otoliths recovered from Gertrude Cove, 25 are complete, and 23 of which are in good to excellent condition; 35 can be identified as *Gadidae,* and of these 19 to *Gadus macrocephalus*, one is distinctively not of the *Gadidae* family (possibly *Hippolglossus*) and the remaining three cannot be identified due to fragmentation, but demonstrate probable *Gadidae* attributes. Of the 75 otoliths collected from Witchcraft Point, six are complete and the remainder are incomplete or heavily fragmented; 34 are identifiable to family *Gadidae* and of these eight can be confidently identified to *Gadus macrocephalus,* the remainder are either undetermined at present or unidentifiable due to heavy fragmentation and/or poor preservation. A sample of the more complete Witchcraft Point otoliths is provided in Figure 5.3, and when compared to the Gertrude Cove otoliths presented in Figure 5.1., the difference in preservation between the two sites is evident.

**Table 5.3. Kiska Island otoliths by site and nearest taxonomic identification.**

| **Taxonomic Identification** | **Witchcraft Point** | **Gertrude Cove** | **Total** | **%** |
|---|---|---|---|---|
| ***Gadidae* spp.** | 26 | 16 | 42 | 37 |
| ***Gadus macrocephalus*** | 8 | 19 | 27 | 24 |
| **Undetermined/Unidentified** | 41 | 4 | 45 | 39 |
| **Total** | 75 | 39 | 114 | 100 |


**Figure 5.3: Sample of Witchcraft Point Otoliths.**

The Pacific cod otoliths range in size from 19.1 to 26.7 mm in length for complete otoliths (averaging 22.1 mm), 10.8 to 14.4 mm in width (averaging 12.2 mm), and 3.4 to 5.2 mm in thickness (averaging 4 mm). Size measurements are summarized in Table 5.4. There is no significant variation in otolith size between sites. The total fish length based on complete otoliths, as calculated using the regression formula for *Gadus macrocephalus* (FL=4.51(OL)-22.97, $r^2$=0.883) by Harvey et al. (2000), ranges from 59.5 to 91.8 cm, with an average length of 71.3 cm. Although there are issues calculating total fish length from otolith length for archaeological contexts, due to deterioration and fragmentation, they are provided here but can be considered estimates only.

**Table 5.4. Pacific cod otolith measurements and estimated total fish length**

| Value Type | Length | Width | Thickness | Total Fish Length |
|---|---|---|---|---|
| **Minimum** | 19.1 | 10.8 | 3.4 | 59.5 |
| **Maximum** | 26.7 | 14.4 | 5.2 | 91.8 |
| **Mean** | 22.1 | 12.2 | 4 | 71.3 |

**Table 5.5. Pacific cod microstructure results: estimated age and season of capture**

| Otolith | Side | Fish Age | Season | Unit | Level |
|---|---|---|---|---|---|
| K-01 | R | 11+ | Warm | 2 | 26 |
| K-02 | L | 7+ | Warm | 2 | 26 |
| K-08 | R | 9+ | Warm | 4 | 2 |
| K-09 | R | 6+ | Warm | 2 | 5 |
| K-12 | L | 8+ | Warm | 2 | 10 |
| K-17 | L | 9 | Cold | 2 | 10 |
| K-20 | L | 8 | Cold | 2 | 13 |

Table 5.5 presents estimated ages and season of capture based on microstructure results (refer to Table 6.3 for associated radiocarbon dates). One year of otolith growth is assumed to be represented by a pair of subsequent opaque and transparent bands, expressing a full seasonal cycle or one year. For this study, a transparent marginal band (winter) represents the closure of the annual cycle, and additional opaque (summer) growth at the margin, represented here by the plus symbol (+), indicates additional growth beyond the fish's age in years. The terms summer and winter are used in the presentation of the results to describe these opaque and translucent patterns of growth and to be consistent with the literature. The use of these terms is simplified and does not directly correlate to season of capture or season of site occupation, but represents patterns of fish growth, which is influenced by a variety of physiological and environmental factors. Of the total seven otoliths, five demonstrate a warm or summer season of capture

based on opaque material along the margin and two otoliths indicate a cold or winter season of capture.

Fish age, as estimated from annular marks of sampled otoliths, ranges from approximately 6+ to approximately 11+ years. As discussed earlier, Pacific cod otoliths are arguably the most difficult Pacific groundfish to age. However, the primary Pacific cod otolith reader for this project, Johnston (personal communication 2013), found these archaeological otoliths to have increased clarity in banding patterns compared to their modern counterparts, which facilitated the aging and interpretation process. This indicates a variation in otolith development of this species over time. However, checking (bands that are nearly identical to annular marks but represent other sub-annular physiological events) is still evident in these otolith thin sections, and presents a significant challenge to interpretation. The excellent condition of these otoliths compared to other archaeological samples also allows for greater confidence in the aging process and in assigning season of capture. For example, with Van Neer et al.'s (1999:117) collection of archaeological tilapia otoliths, 80% of the otoliths had unreadable black margins due to recrystallization.

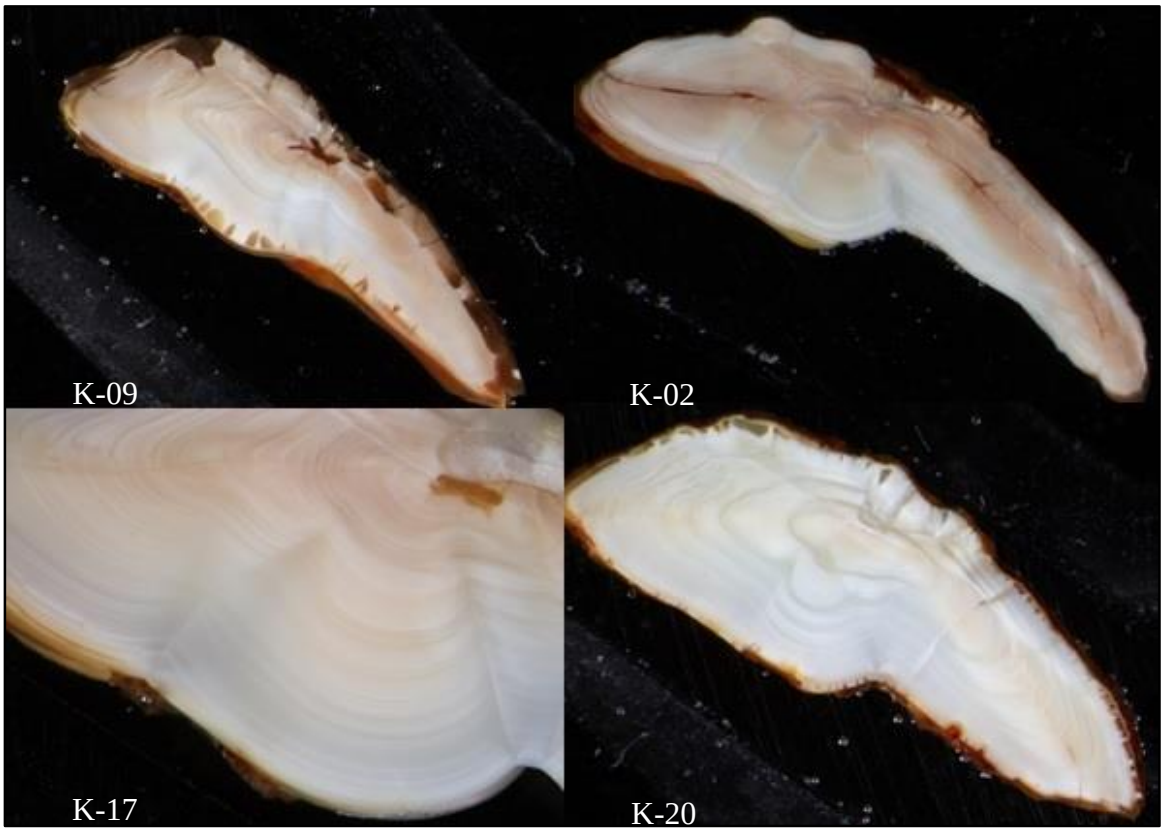



**Figure 5.4: Gertrude Cove otolith thin sections K-09, K-02, K-17, and K20. Photo modified from Chris Johnston.**

Figure 5.4 demonstrates a sample of otolith thin sections. No scale was available for this figure. Otoliths K-01, K-12, K-17, K-20 from Gertrude Cove have notably clear and distinct banding patterns. K-09 (Figure 5.4), although relatively clear with distinctive annuli, has areas of structural alteration and discolouration (visible in Figure 5.4 as discoloured patches, especially along the otolith margin. These areas were avoided for sampling purposes, and further sampling of these areas could aide in determining the nature of the structural transformation. Otolith K-02 (Figure 5.4) has numerous checks and threading throughout, especially towards the margin. Substantial checking,

particularly during immaturity, is most evident in otolith K-17, and otolith K-20 (Figure 5.4) best represents an otolith within minimal checking.

### 5.2. Atlantic Cod Morphological and Microstructure Analysis Results

Atlantic cod otoliths were initially analyzed as a component of this study due to their accessibility, and were used to develop the methodological and interpretative framework to address the Pacific cod otoliths. A total of 23 modern Atlantic cod and 36 archaeological Atlantic cod were analyzed to successfully develop a methodological and interpretative framework for this project. Of the 23 modern Atlantic cod, 12 were thin sectioned and initial age estimates were completed. Of the 12 thin sectioned otoliths, four were age verified and micromilled for isotope analysis. This small number is due to time and budget constraints as well as the focus of the project, which is on the Pacific cod otoliths from Kiska Island. These range in age from 4 to 5+, and microstructure analysis indicates that two were harvested in the summer and two in the winter.

A total of 36 archaeological otoliths recovered from the 17$^{th}$ century fishing settlement of Ferryland, Newfoundland were also analyzed. The otoliths were recovered from a two room service wing consisting of the buttery/pantry and kitchen associated with the complex of buildings identified as the Mansion House. The otoliths are from contexts dated between 1620 and 1696 (Barry Gaulton personal communication 2015). These otoliths represent the total available otoliths for analysis from Ferryland, and selection for stable isotope analysis was based on preservation.

Thirty-four otoliths can be identified to family *Gadidae*, and of these 20 can be positively identified as *Gadus morhua*, and the remaining 14 could not be

morphologically distinguished by this researcher between *Gadus morhua* and *Gadus ogac* (Greenland cod). Two otoliths remain unidentified. Overall the otoliths from Ferryland are in relatively good condition for archaeological otoliths. However, as Figure 5.5 demonstrates, these otoliths are not as well preserved as those recovered from Kiska Island, especially from Gertrude Cove.

Preservation issues include the lack of a retained outer margin due to deterioration and an overall delicate chalky/flaky consistency, which could be a result of burning or diagensis (Andrus and Crowe 2002:296). Of the 36 otoliths, 21 are mostly complete, and the remainder range from incomplete to heavily fragmented. Of the complete otoliths, five are in good condition and retain most of the outer otolith margin. Further analysis of this otolith assemblage will require alterations to the sampling strategy to address issues related to marginal deterioration, for example with an increased focus on core (1S-1W) values as opposed to edge material.


**Figure 5.5: Sample of otoliths from Ferryland, NL.**

Complete length for the Ferryland archaeological Atlantic cod otoliths ranges from 12.36 to 15.34 mm (mean 15.05 mm), width ranges from 5.55 to 6.98 mm (mean 6.92 mm), and thickness from 1.8 to 2.73 mm (mean 2.46 mm), and weight 149 to 331mg (mean 317.50 mg). Five Ferryland otoliths were thin sectioned and an age estimate was completed, and age verification and micromilling was completed for four (Table 5.1). Ages range from 4+ to 6+/7, with one otolith visually confirming winter catch and two confirming summer season of catch (Table 5.6). The remaining otolith has an unclear

margin, but appears to have some transparent edge growth representing a winter season of catch (Figure 5.6; no scale is available for this figure).

**Table 5.6. Microstructure results of Atlantic cod from Ferryland, NL: estimated age and season of capture**

| Otolith | Side | Fish Age | Season | Event | Context | Date |
|---|---|---|---|---|---|---|
| F-02 | L | 6 | Cold | E765 | Builder's trench (kitchen/buttery/pantry) | 1620s |
| F-06 | L | 4+ | Warm | E765 | Builder's trench (kitchen/buttery/pantry) | 1620s |
| F-13 | L | 6+/7 | Cold | E634 | Collapse of buttery/pantry | 1620s-1696 |
| F-21 | L | 6+ | Warm | E785 | Buttery/pantry occupation level | 1620s-1696 |

**Figure 5.6. Thin section image of otolith F-13, age 6+/7.**

### 5.3. Mineral Structure Analysis Results (FTIR)

The quality of isotope data is potentially dependent on the mineral structure of the otolith as it has the potential to affect the $\delta^{18}O$ and $\delta^{13}C$ composition of the otolith (Andrus and Crowe 2002). Additionally, little is understood about the patterns of archaeological otolith mineral structure and recrystallization. As a result, Fourier Transfer Infrared spectroscopy (FTIR) was used in this study to identify the mineral structure (refer to Section 4.3.3 for method). All otoliths sampled for isotope analysis (n=15) were also analyzed using FTIR, totalling 40 samples of ~100µg. Results were measured against known aragonite and calcite spectra (Adler and Kerr 1962; Weiner 2010:8) and in consultation with experienced spectra interpreters.

This analysis illustrates that all sampled otoliths are predominately aragonite with a diagnostic calcite peak (at ca. wavenumber 1625, see Figure 5.7). Despite this diagnostic calcite peak, the otoliths can be considered pure aragonite (Kris Poduska personal communication; Weiner 2010:8). Interestingly, there is no evidence of patterned structural variation based on species, antiquity of otolith, nor depositional environment. The pure aragonite structure with the diagnostic calcite shoulder is consistent for all sampled otoliths representing both species of cod as well as modern, historic, and prehistoric samples. Additionally, sampling was conducted at various locations, ranging from the core to the edge of the otolith, demonstrating intra-otolith uniformity. This result also diminishes the potential that the otoliths were exposed to direct burning to the extent that it alters the isotope values, as it results in complete recrystallization from aragonite to calcite (Andrus and Crowe 2002:296).

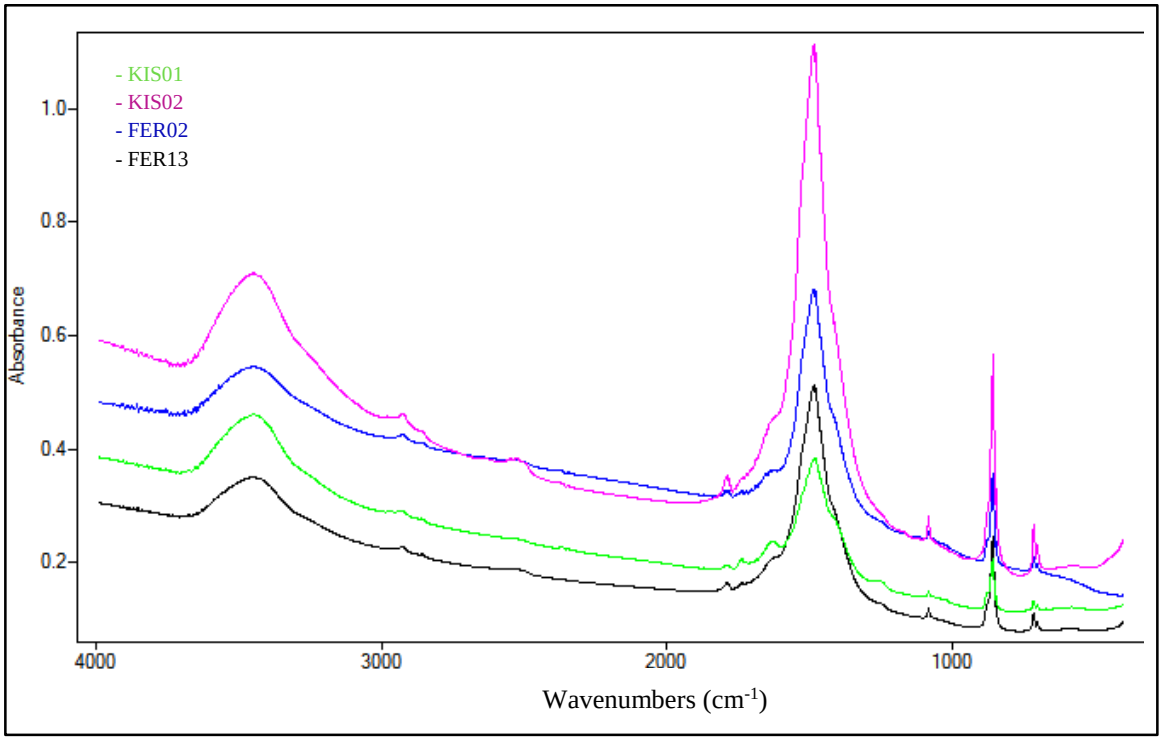



**Figure 5.7 FTIR spectra for a sample of historic archaeological Atlantic cod and prehistoric archaeological Pacific cod otoliths demonstrating correlating diagnostic peaks (KIS01, KIS02, FER02, and FER13).**

There is limited literature on archaeological otolith spectra, and the potential and structure of recrystallization during deposition is poorly understood. Other studies do not provide their data but conclude, through XRD, that all analyzed otoliths, which include freshwater drum (*Aplodinotus grunniens*), Pacific cod, and *Gobiidae* spp. and *Citarichtidae* spp., are pure aragonite (e.g., Pellegrini and Longinelli 2008:122; West et al. 2012; Wurster and Patterson 2001:85) Additionally, Andrus and Crowe (2002) demonstrate that recrystallization occurs from direct and prolonged exposure to high temperatures.

Although this method adequately identified the aragonitic structure of the otoliths, the results only provide relative quantities of the material. Further analysis with XRD would allow for the quantification of the calcitic content, and as noted in Chapter 4,

interpretation of the infrared spectra of a sample is complex and requires an exhaustive understanding of the material and spectra ranges. This research represents the simplified version of measurement analysis, and relied heavily on the support of Poduska and Xu (of the Poduska Research Group, Experimental Materials Physics and Chemistry, MUN) using best fit within the spectra, and further analysis and interpretation can be conducted.

### 5.4. Pacific Cod $\delta^{18}O$ and $\delta^{13}C$ Results

All $\delta^{18}O$ and $\delta^{13}C$ values are reported in standard $\delta$ notation relative to the VPDB (Vienna Pee Dee Belemnite) reference and presented as per mil (‰) values with an analytical precision of ±0.05‰ for $\delta^{18}O$ and ±0.03‰ for $\delta^{13}C$. The $\delta^{13}C$ values are briefly discussed, excluding the modern Atlantic cod samples, which did not produce sufficiently reliable results for discussion. All values are presented in Appendix B.

Of the total 118 Pacific cod subsamples from seven otoliths (see Table 5.1), $\delta^{18}O_{otolith}$ values range from +1.70 to +3.02 ‰[4], a $\bar{x}$ of 2.35‰, and a range of 1.49‰ (n=129). This range is relatively narrow for $\delta^{18}O_{otolith}$ distributions, indicating the fish were either exposed to ambient water within a small geographical region, had high site fidelity, or are of the same breeding stock (Gao et al. 2005; e.g. Kastelle et al. 2012). Otolith K-09 demonstrates the most clustered values, with a range of 0.44‰, and otolith K-17 is the most dispersed with a range of 1.03‰. An averaged distribution is presented in Figure 5.8 and all $\delta^{18}O$ values are displayed in Figure 5.9.

[4] Maximum value of +3.19‰, but is considered unreliable due to sample size issue.

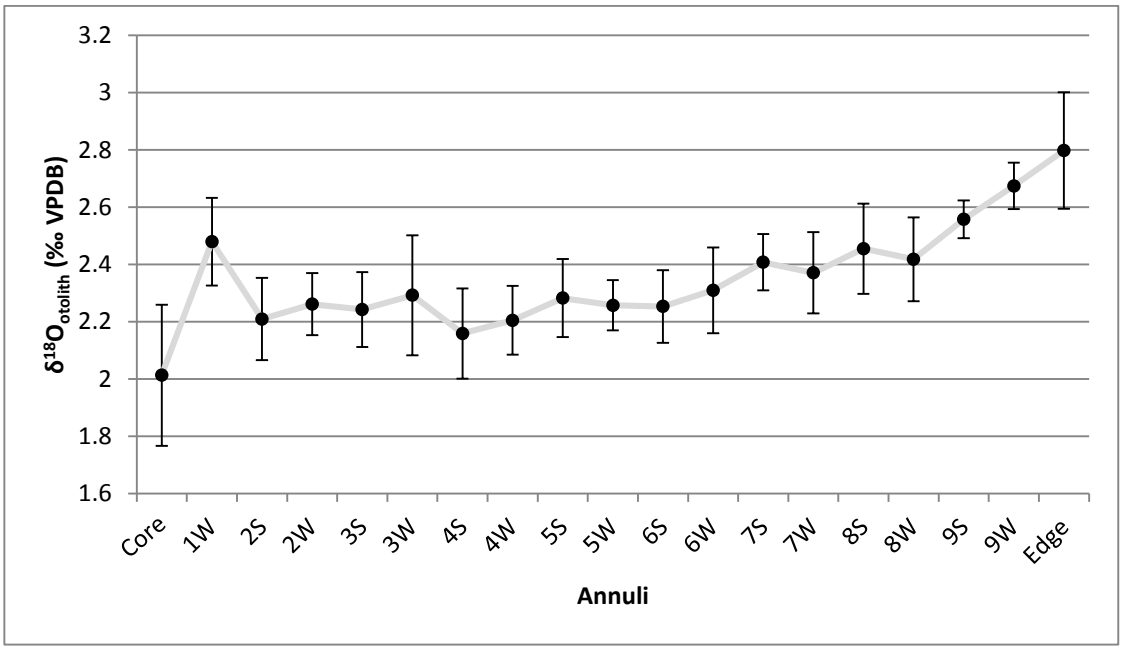



**Figure 5.8: Average Sub-Annual $\delta^{18}O$ values of Kiska Island archaeological Pacific cod otoliths.**

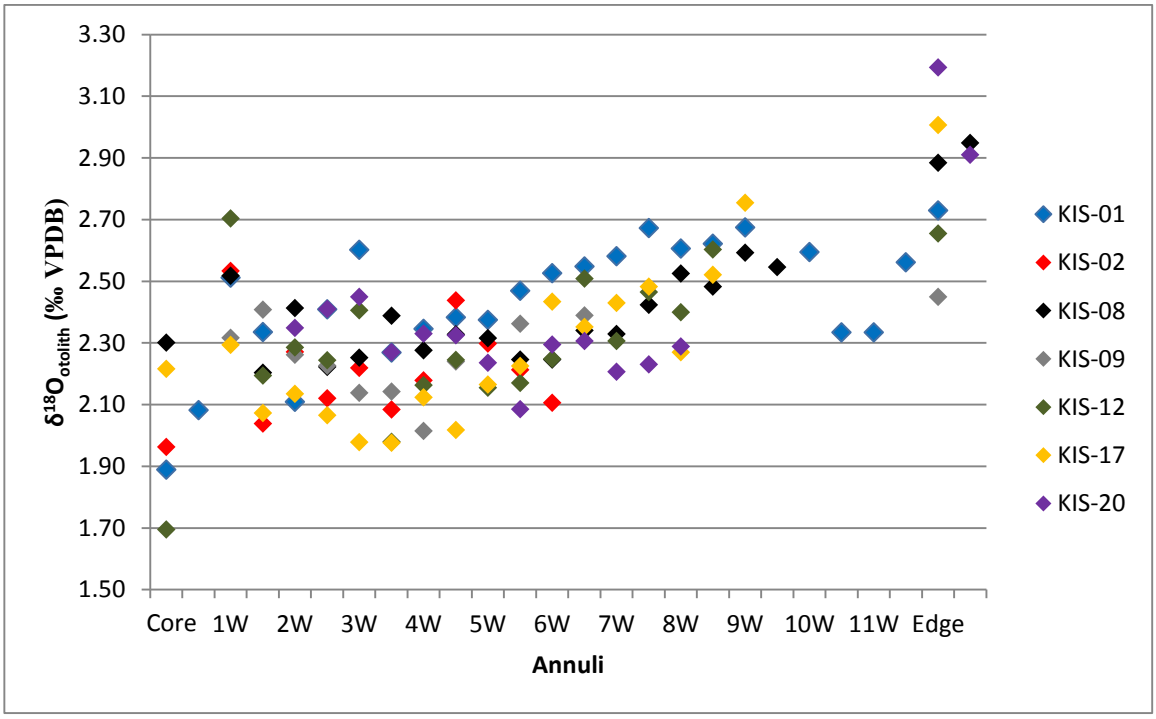



**Figure 5.9: The $\delta^{18}O$ values of Kiska Island archaeological Pacific cod otoliths by annuli**

Overall, these otoliths show a weak pattern of cyclical seasonal peaks and possess a narrow range of values, demonstrating a lack of patterned inter-seasonal variation and minimal overall variation in ambient water conditions. Otolith K-17 (Figure 5.10) partially displays cyclical inter-seasonal variation, but it is not consistent throughout the otolith, and the values are heavily clustered, with a range of 1.03‰. This range equates to approximately 4°C (equation from Helser and McKay 2013), which is below the approximately 8°C seasonal variation of Northwest Pacific Ocean SST, but is consistent with the temperature range of ~2-4°C at a depth of 120-400 m in the water column (Max et al. 2012:3; Riethdorf et al. 2013). Otolith K-12 (Figure 5.11) demonstrates a more expected distribution pattern (e.g. Gao et al. 2005; Helser and McKay 2013) with lower $\delta^{18}O$ core values and an increase towards the second and third years. However, K-12 does not demonstrate the expected subsequent decrease in $\delta^{18}O$ and instead increases towards the margin. This trend is consistent for all samples except for K-02, which does not have usable edge values.

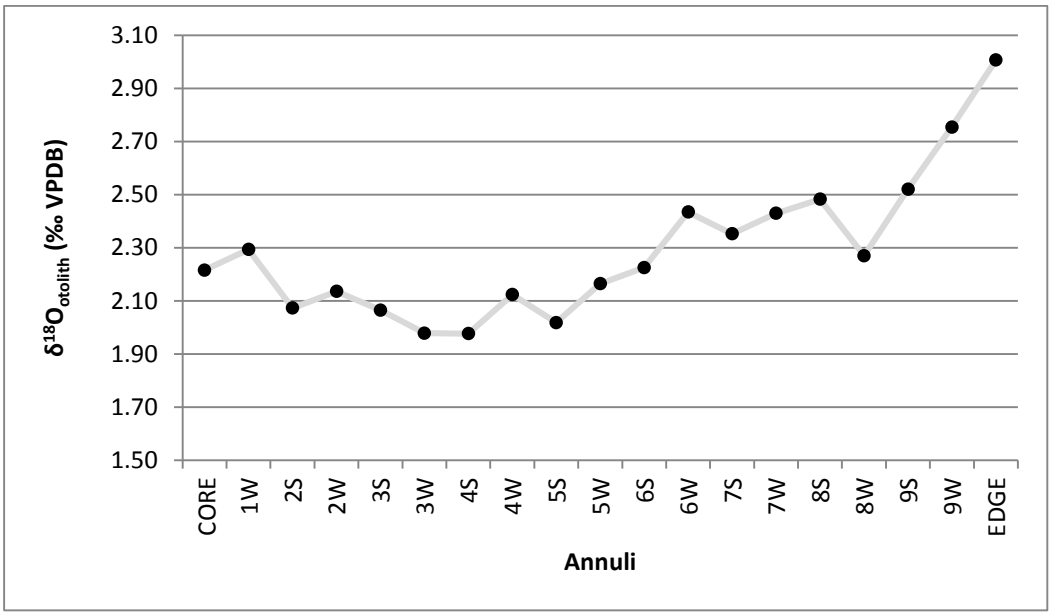



**Figure 5.10: The $\delta^{18}O$ values of Kiska Island archaeological Pacific cod otolith K-17**

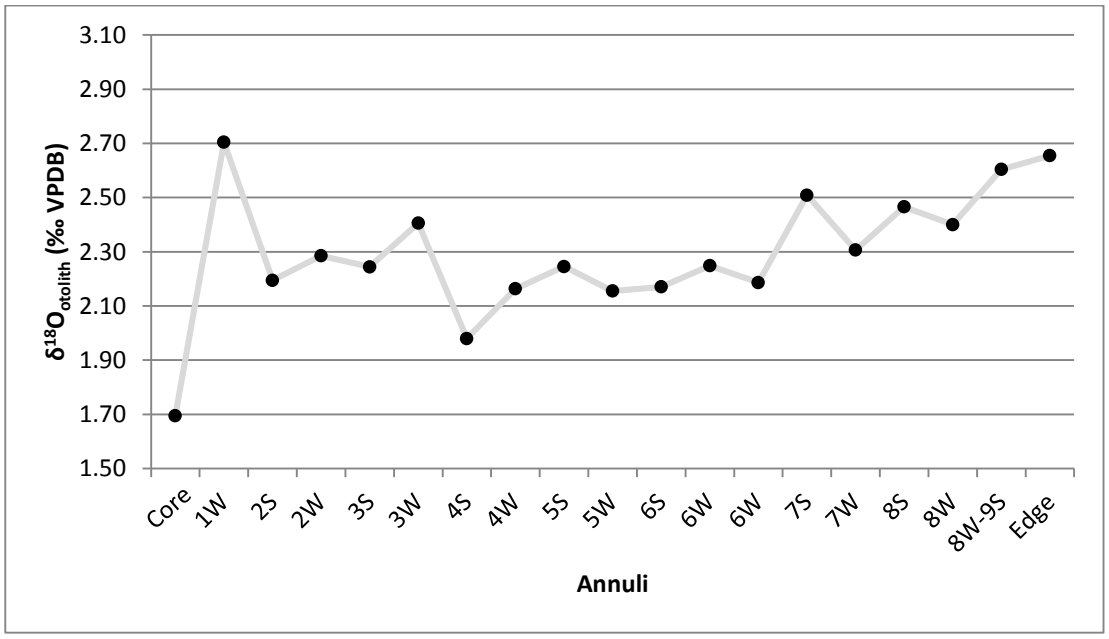



**Figure 5.11: The $\delta^{18}O$ values of Kiska Island archaeological Pacific cod otolith K-12**

Variation[5] ranges from 0.00‰ to 1.01‰ (K-12 1S to 1W), with an average sub-annual variation of 0.15‰. The most significant seasonal shift occurs from the core (1S,

[5] Difference in values from one consecutive sub-annual warm/cold band to the next, does not include values for non-consecutive annuli

$\overline{x}$ = 2.0‰, n=5) to the next consecutive annuli (1W, $\overline{x}$ = 2.48‰, n=6). Overall, values then gradually increase from the second opaque band (2S), with isolated points of decrease, to reach seasonal maxima, and minimum water temperatures, at the otolith margin (edge)[6].

The minima, which correspond to warmest ambient water temperatures, occur at the core or first summer (1S), as well as at the 4th year and the 6th year. Of otoliths with available core values (n=5), three otoliths (K-01, 02, 12) display minima at the core (1S), with an additional otolith (K-08) demonstrating only slightly (0.10‰) lower values for the second summer than at the core. This pattern is in contrast to other Pacific cod studies of modern otoliths (e.g. Gao et al. 2005; Helser and McKay 2013) that demonstrate depleted core values, a sharp increase at age 2/3, and then a gradual decrease towards the margin.

Similarly to previous findings for Atlantic cod otoliths, $\delta^{18}O_{otolith}$ values for Pacific cod have recently been demonstrated to vary by 0.21‰/1°C (Gao et al. 2001; Helser and McKay 2013:5). Based on the working fractionation equation used in these recent studies as outlined by Gao et al. (2001) and Helser and McKay (2013:5), the $\delta^{18}O_{otolith}$ demonstrate a range of 0 to 4.8°C with an average inter-seasonal variation of 0.73°C (±0.23, n=108). Edge values range from 2.49 to 3.19‰, representing a 3.5°C temperature variation between all edge values. The significant seasonal shift identified here, from core to the first opaque band, represents an average of a 2.29°C shift in ambient water temperature.

[6] Edge values not available for KIS-02

Although this study primarily focuses on the $\delta^{18}O$ values, the $\delta^{13}C$ values are briefly addressed in the discussion and presented here. The Gertrude Cove cod $\delta^{13}C_{otolith}$ values range from -2.5‰ to -0.3‰[7] with a mean of -1.2.‰. Initial values range from -2.5‰ to -1.11‰, followed by a spike within the first year to an average -0.97‰, and subsequent lower values again at the second summer. This is followed by a selection of otoliths representing less variable values (K09, K17) at around year 3/4. In contrast, other otoliths demonstrate continuously decreasing values (K08, K20), and others (K01, K02, K12) have irregular isotope patterns, illustrating the variability either in diet or environment between individual fish. Maximum values occur between year 2 and edge values, averaging a 2W-3W maxima, and range from -0.80 to -0.03‰. Figure 6.1 illustrates the mean $\delta^{13}C$ values, and all values are presented in Figure 5.11.

[7] Outlier (+0.16) excluded

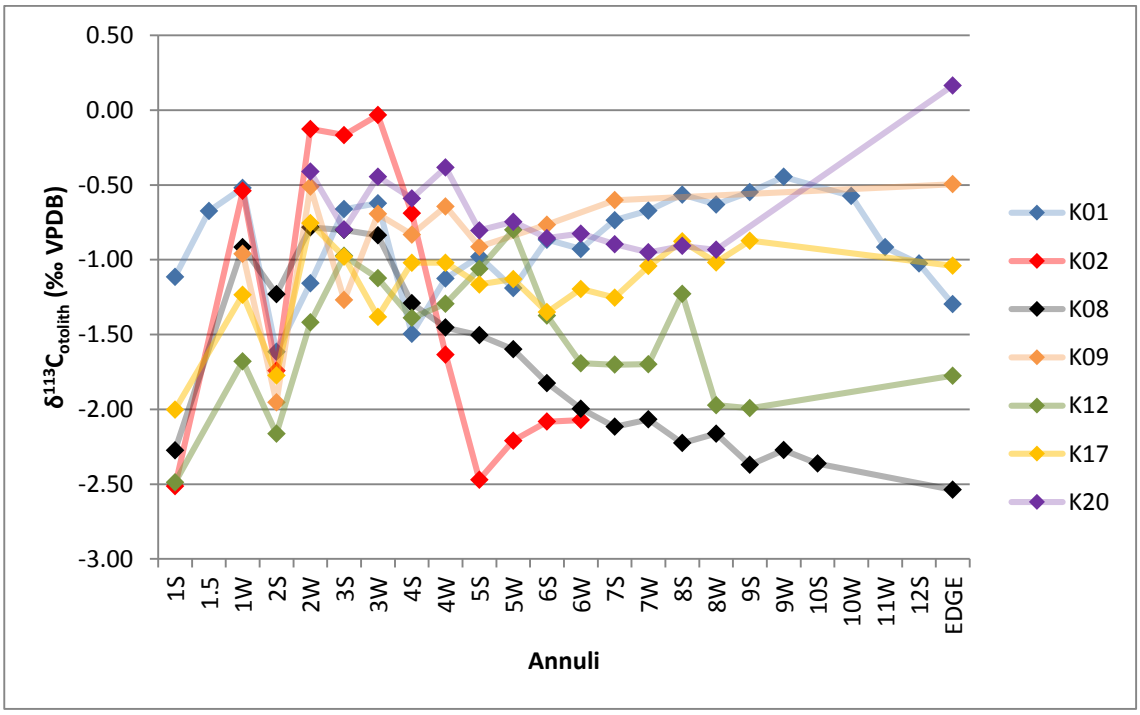



**Figure 5.12: The $\delta^{13}C$ values of Kiska Island archaeological Pacific cod otoliths by annuli**

### 5.5. Atlantic Cod $\delta^{18}O$ and $\delta^{13}C$

Atlantic cod $\delta^{18}O_{otolith}$ values range from -0.12 to +2.97‰. The modern samples range from +0.12 to +2.92‰ ($\overline{x}$ +1.9, n=34), while the archaeological samples range from -0.12 to +2.97‰ ($\overline{x}$ +1.82, n=36). All values are presented in Appendix B. Further discussion is based primarily on the archaeological otoliths. For the North Atlantic, the relationship between temperature and $\delta^{18}O_{otolith}$ is generally 0.2‰/1°C ambient water temperature (Gao et al. 2001; Grossman and Ku 1986; Thorrold et al. 1997; Weidman and Millner 2000).

The range for archaeological Atlantic cod otoliths from Ferryland is 3.09‰, which equates to a 15.45°C range in temperature. The average range between all values is 10.2°C (n=36). Otolith F-02 has the most clustered values with a range of 1.37‰

(6.85°C), and otolith F-06 is the most dispersed with a range of 2.8‰ (14.1°C). Seasonal variation[8] ranges from 0‰ to 1.73‰ (8.65°C), with an average seasonal variation of 0.59‰ (2.7°C).

Only two otoliths have core and juvenile values, and for these otoliths the seasonal variation is highest between the core and first winter (F-06) and first winter and second summer (F-13); the other two otoliths without usable core values demonstrate the highest seasonal variation around the third and fourth years, respectively. As is seen in Figure 5.13 these values are widely dispersed, and do not clearly demonstrate cyclical seasonal patterns or markers of maturity as can be expected of modern Atlantic cod (e.g. Gao et al. 2001; Jamieson et al. 2004).

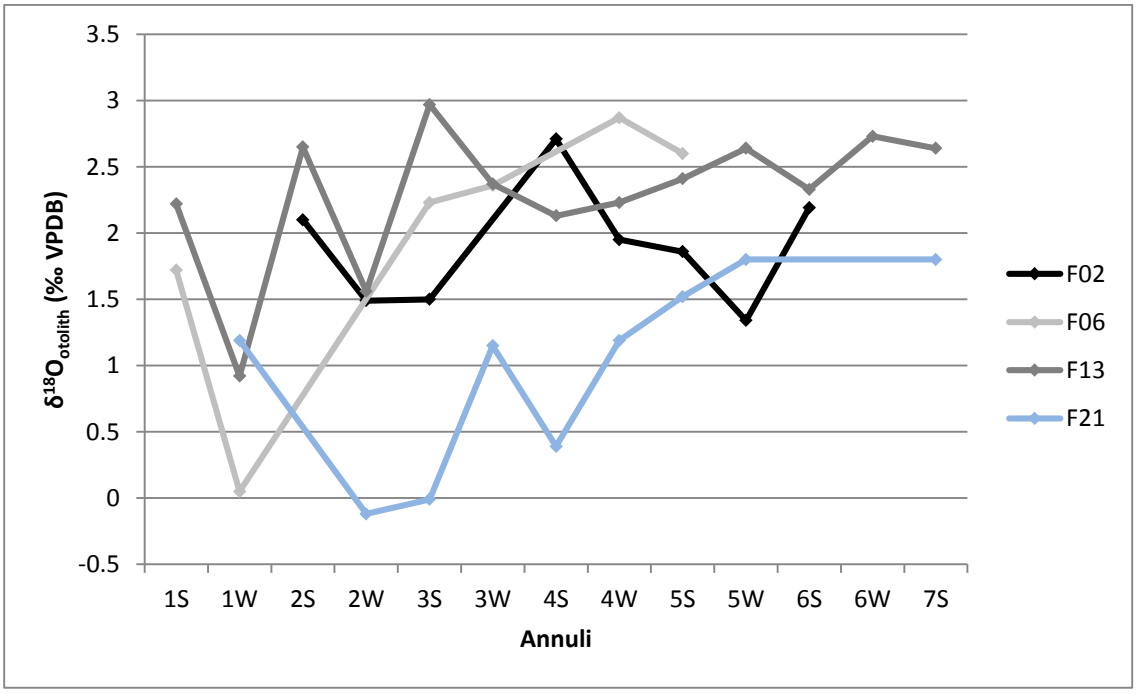



**Figure 5.13: The $\delta^{18}O$ otolith values of archaeological Atlantic cod from Ferryland, NL**

[8] Difference in values from one consecutive season (band) to the next, does not include values for non-consecutive annuli

The minima (warmest ambient temperatures) are all sampled from transparent annuli, with two otoliths demonstrating minima at the first winter, one at the second winter, and one at the fifth winter. Maxima are from both summer and winter growth annuli, ranging between the fourth summer and the fifth winter. Otolith F-13 (Figure 5.14) is the only otolith that demonstrates a clear cyclical seasonal variation during immaturity with eventual tapering of values at maturity (ca. age 4) and above. The wide distribution and variability of these otoliths, combined with the small sample size, prevents the identification and discussion of additional patterns. However, this lack of identifiable patterns is further discussed in Chapter 6 (Section 6.7).

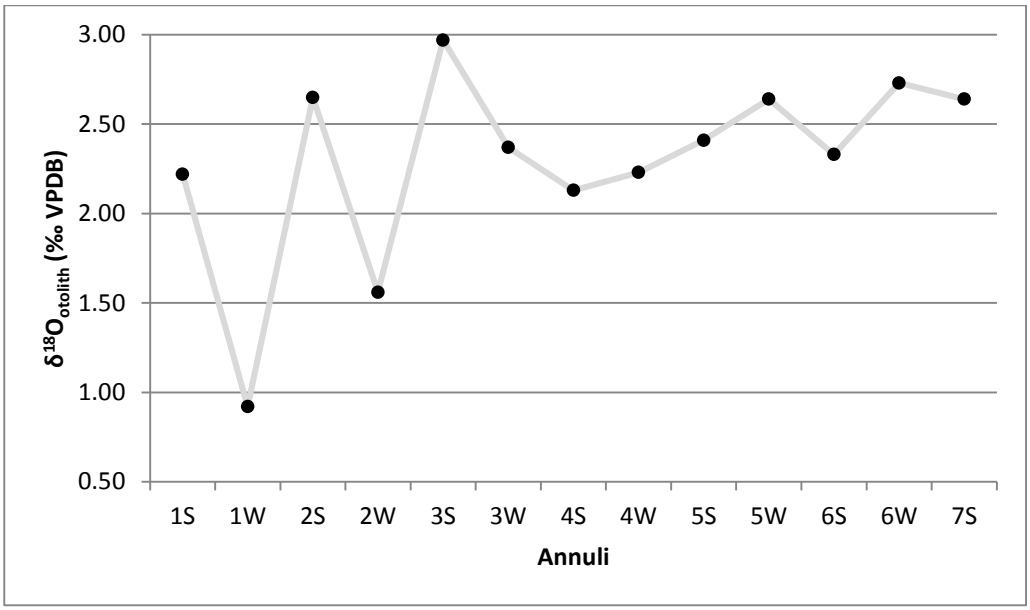



**Figure 5.14: The $\delta^{18}O$ otolith values of archaeological Atlantic cod otolith F-13 from Ferryland, NL**

The Ferryland cod $\delta^{13}C$ values range from -2.93 to -0.62‰, with a mean of -1.43‰ (n=35) (Figure 5.15). Initial hatch values range from -3.9 to -1.95‰, followed by continuously increasing values within the first three years, and a relative stabilization (-1.38 to -0.03‰) for the remainder of the cods' life. Similar to Jamieson et al. (2004),

there are aberrant values, which can be expressions of individual dietary preference and metabolism. $\delta^{13}C$ maxima has been demonstrated to be an indicator of age of maturity (Schwarcz et al. 1998; Gao et al. 2001:451). Seasonal maxima for these samples range from year 4 (F06) to year 5 (F03, F13, F2), with a range in values of -0.03 to -0.81‰.

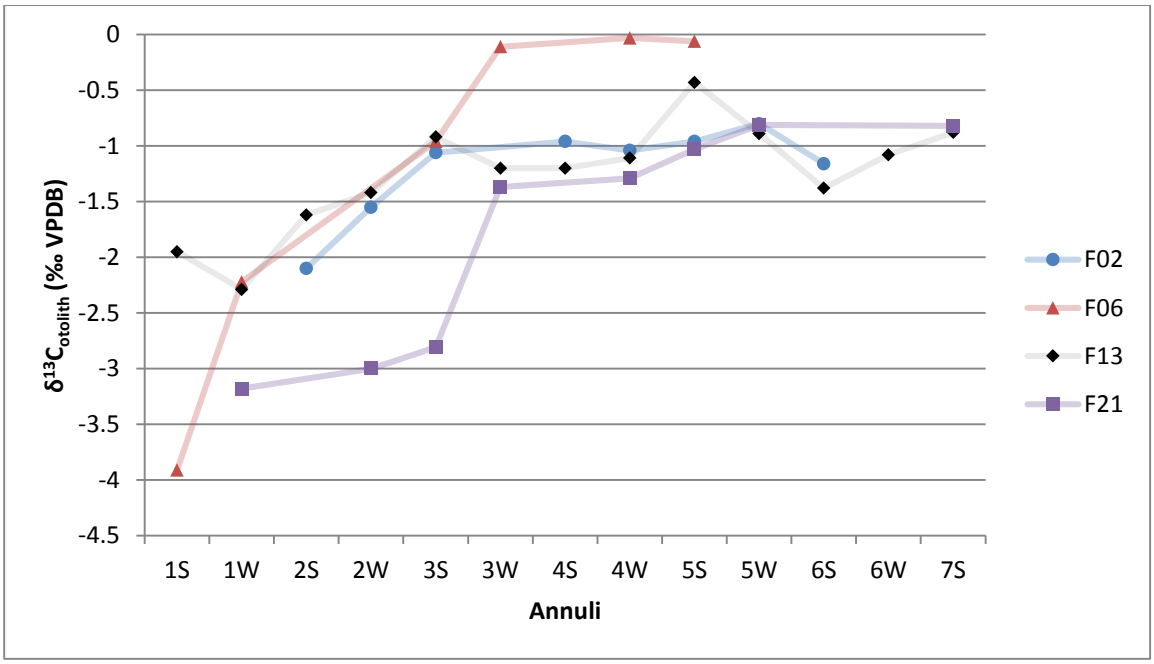



**Figure 5.15: The $\delta^{13}C$ values of archaeological Atlantic cod otoliths from Ferryland, NL**

Modern Atlantic cod $\delta^{18}O$ values have a range of 2.8‰. This range is narrower than the archaeological Atlantic cod, and there is an overall pattern of an increase in values from core to edge of the otolith, which is not seen in the archaeological samples from Ferryland. Sub-annual shifts are most pronounced from the second summer to winter (R01, 06) and from the fifth summer to winter (Ref-07, Ref-09). The seasonal maxima (2.53-2.92‰) or coldest temperatures occur between the fourth and fifth years for all otoliths (4S, 4W, 5W, 5S), and seasonal minima (0.12-1.64‰) occurs at the first

year. Overall seasonal variation ranges from 0.06‰ to 1.23‰ with an average of 0.44‰ (n=28). The results are presented in Figure 5.16.

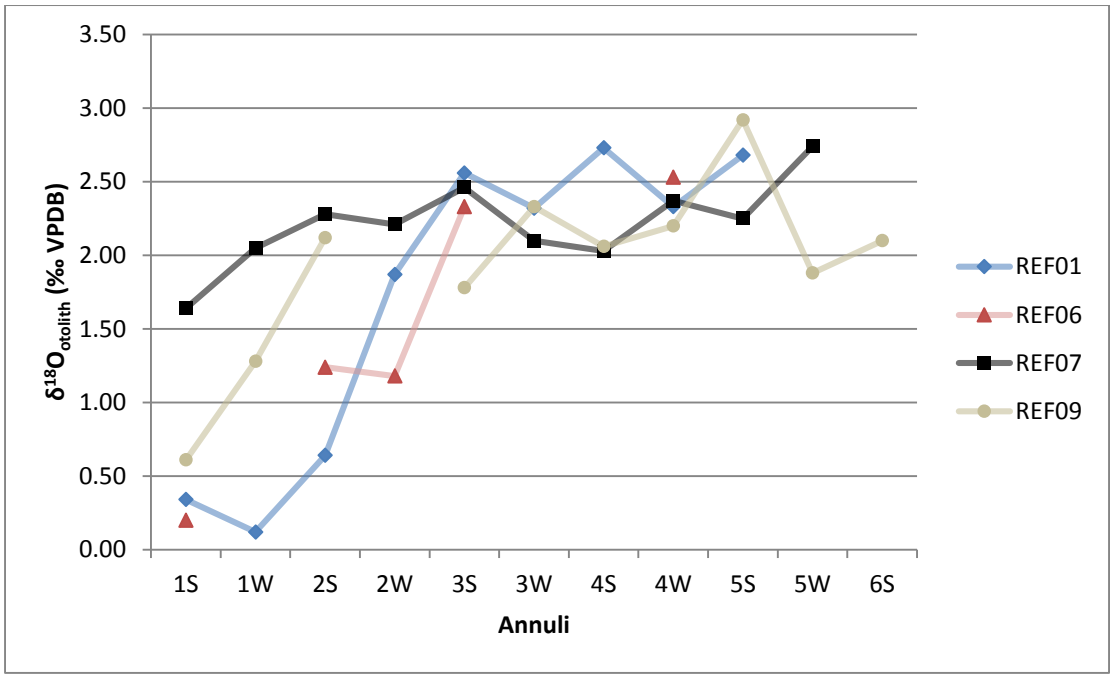



**Figure 5.16: The $\delta^{18}O$ values of a sample of modern Atlantic cod otoliths**

Similarly to the archaeological Pacific cod, the modern Atlantic cod $\delta^{18}O$ values gradually increase from the core to the otolith margin, with some evidence of cyclical seasonal variation (Figure 5.16). Otolith Ref-01(Figure 5.17) best demonstrates the pattern of seasonal variation, as well as presenting the expected lower values at hatch with subsequent increase in the consecutive annuli. The $\delta^{18}O$ values of otolith Ref-07 (Figure 5.18) differs from the other modern Atlantic cod in this study. Otolith Ref-07 has a tighter range and the values are significantly higher in comparison, at 1.3 to 1.44‰ higher or ~6.85°C, lower at first summer than other otoliths. Due to the young age of the fish represented in this sample, trends related to pre and post maturity cannot be identified.

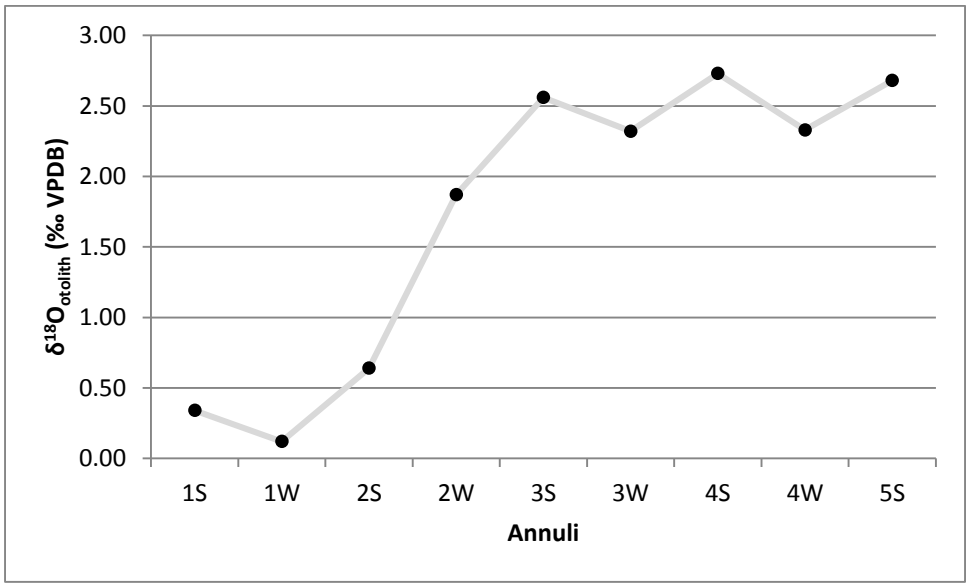



**Figure 5.17: The $\delta^{18}O$ otolith values of modern Atlantic cod otolith Ref-01**

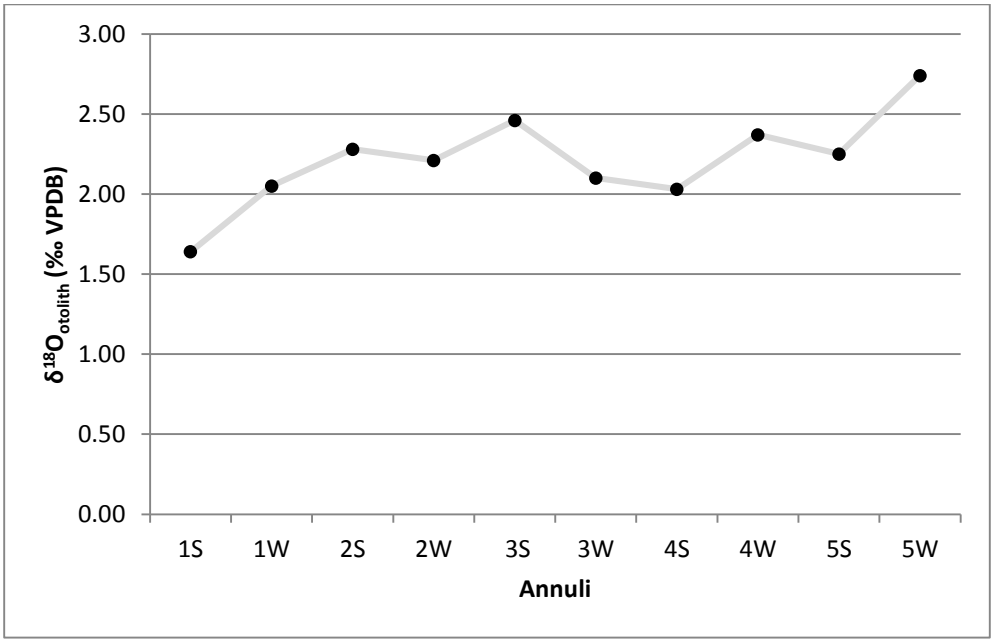



**Figure 5.18: The $\delta^{18}O$ otolith values of modern Atlantic cod otolith Ref-07**

### 5.6. Radiocarbon Results

Radiocarbon samples were run at the Carbon Cycle Accelerator Mass Spectrometry Laboratory at the University of California, Irvine (UCIAMS). The CALib online database (Stuiver and Reimer 2013) was used to calibrate all dates presented here to years before present (BP) at both the 1-sigma and 2-sigma ranges. Charcoal samples were collected in the field from arbitrary levels, and based on soil descriptions and wall profiles were correlated to stratigraphic layers. Samples were also taken from distinct soil lenses and layers.

Radiocarbon dates for Gertrude Cove and Witchcraft Point are presented in Tables 5.6 and 5.7 and represent just over 2000 years of discontinuous occupation, indicating two or possibly three distinct settlement periods. At Gertrude Cove, sterile soil was reached at a depth of ~4.5 m depth below datum (dbd). Immediately above sterile soil, represented by Levels 24-29 is the earliest occupation cluster with dates ranging from a maximum 2377 to 2704 cal BP. This occupation is followed by a 428 year gap, which is potentially manufactured by the lack of available dates in the sequence for Levels 22 and 23 (~3-3.3 m dbd) and wall profiles do not indicate any clear discontinuity in occupation. This is followed by another ~1000 years of occupation represented by two available dates for Levels 20 and 21, with a maximum date range of 1864-1949 cal BP.

Following this is a ~1200 year gap between Levels 18 and 20, at ca 2.5-2.7 m dbd. The most recent occupation consists of the upper ~2.5 m of the midden and is represented by dates ranging from a maximum 169 to 646 cal BP. There is some evidence of mixing, and the excavation strategy of arbitrary 10-20 cm intervals plays a role, as it obscures events within the strata with cuts and fills, which were both evident during excavation

and in wall profiles. However, as can be seen in Figure 5.19, there are few anomalous dates and the occupation clusters are generally clear and consistent, and are also in agreement with regional chronologies.

**Table 5.7: Gertrude Cove radiocarbon dates and occupation clusters**

| Lab Code | Calibration Program | Site | Unit | Level | C14 Date | Cal BP 1σ | Cal BP 2σ |
|---|---|---|---|---|---|---|---|
| UCIAMS 112139 | Calib | Gertrude | 2 | 5 | 330 ± 20 | 349-406 | 346-463 |
| UCIAMS 112134 | Calib | Gertrude | 1 | 6 | 600 ± 15 | 591-639 | 585-646 |
| UCIAMS 124960 | Calib | Gertrude | 2 | 8 | 155 ± 15 | 185-219 | 169-224 |
| UCIAMS 124958 | Calib | Gertrude | 3 | 9 | 505 ± 15 | 520-533 | 513-539 |
| UCIAMS 124963 | Calib | Gertrude | 2 | 12 | 630± 15 | 635-652 | 558-603 |
| UCIAMS 112135 | Calib | Gertrude | 2 | 13 | 600 ± 15 | 591-639 | 585-646 |
| UCIAMS 124962 | Calib | Gertrude | 2 | 16 | 605 ± 20 | 588-643 | 580-651 |
| UCIAMS 124961 | Calib | Gertrude | 2 | 18 | 590 ±20 | 597-633 | 586-645 |
| UCIAMS 124959 | Calib | Gertrude | 2 | 20 | 1955 ± 20 | 1881-1925 | 1864-1949 |
| UCIAMS 124965 | Calib | Gertrude | 2 | 21 | 1960 ± 15 | 1887-1925 | 1876-1945 |
| UCIAMS 124967 | Calib | Gertrude | 2 | 24 | 2455 ± 20 | 2634-2696 | 2377-2542 |
| UCIAMS 124966 | Calib | Gertrude | 2 | 25 | 2495 ± 15 | 2505-2591 | 2492-2600 |
| UCIAMS 124964 | Calib | Gertrude | 2 | 28 | 2430 ± 15 | 2376-2487 | 2358-2495 |
| UCIAMS 112355 | Calib | Gertrude | 2 | 29 | 2465 ± 15 | 2637-2696 | 2455-2704 |

**Table 5.8: Witchcraft Point radiocarbon dates**

| Lab Code | Calibration Program | Site | Unit | Level | C14 Date | Cal BP 1σ | Cal BP 2σ |
|---|---|---|---|---|---|---|---|
| UCIAMS 112137 | Calib | Witchcraft | 1 | 5 | 310 ± 15 | 391-427 | 355-434 |
| UCIAMS 112138 | Calib | Witchcraft | 5 | 6 | 345 ± 20 | 320-378 | 316-408 |
| UCIAMS 112140 | Calib | Witchcraft | 6 | 11 | 365 ± 20 | 434-483 | 427-497 |
| UCIAMS 112136 | Calib | Witchcraft | 5 | 11 | 1030 ± 15 | 943-955 | 927-961 |

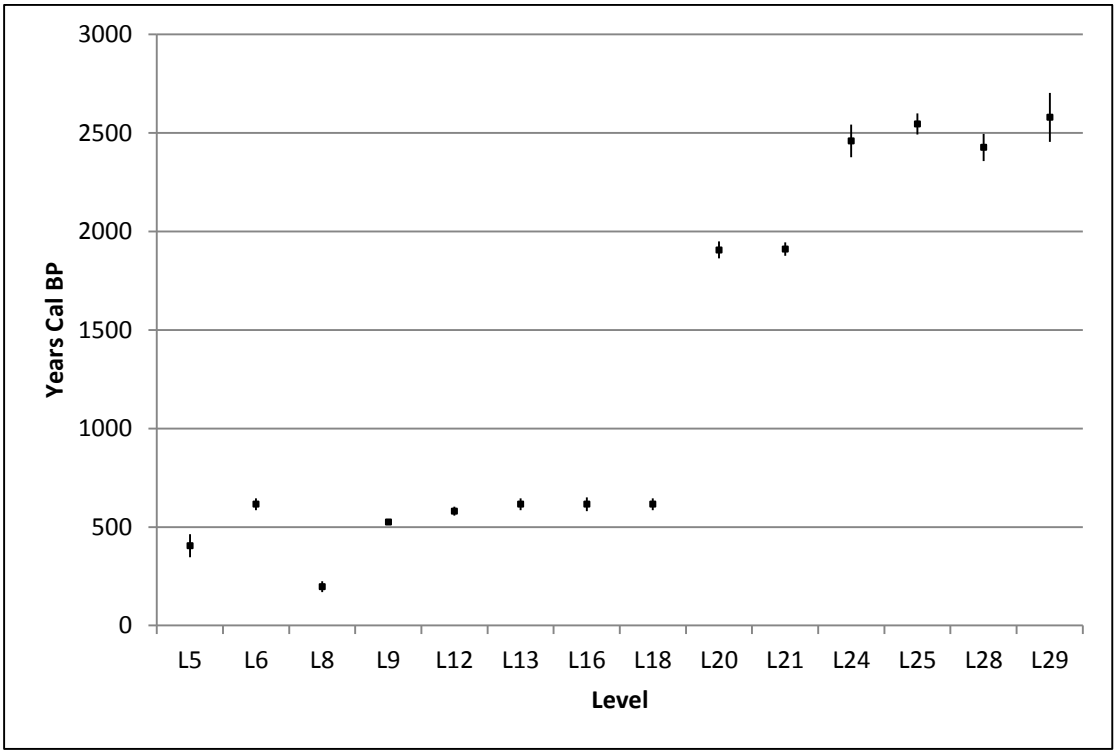



**Figure 5.19: Gertrude Cove radiocarbon dates (cal. BP). Symbols show median 2σ range and probability.**

All charcoal samples are assumed to be from driftwood due the lack of other wood resources on the island, and both sourcing and dating driftwood is potentially problematic (Alix 2005). Preliminary analysis of one charcoal sample was inconclusive (conifer) as it was missing resin canals, which facilitate identification (Jason Miszaniec, personal communication 2013). On neighbouring Amchitka Island, Desautels et al. (1971:13)

noted the substantial amount of available driftwood throughout the island's bays, which they attributed to currents and frequent storms. This is echoed by archaeological and paleoethnobotanical studies of the region (e.g. Bank 1952a; Shaw 2008). Driftwood was collected and identified as a component of Desautels et al.'s (1971) assessment, and the subsequent analysis indicated that all samples originated in North America, which is congruent with the regions prevailing currents (e.g. Alaskan Stream, Alaskan Current). This is in agreement with more recent studies indicating that the main source of driftwood in the Aleutians is from Southeastern Alaska; with cedars, spruces, and hemlocks dominating driftwood assemblages (Wheeler and Alix 2004:1).

Driftwood is a significant resources throughout the Aleutian Islands, and it's presence was an integral factor in settlement and the manufacture of *barbaras* (semi subterranean houses) and *baidarkas* (driftwood frame, skin covered watercraft) (Black 1984:53; Black and Liapunova 1988; Wheeler and Alix 2004) However, it should be noted that driftwood availability is dependent upon a wide variety of environmental factors and fluctuates over time, and Desautels et al.'s (1971) generalized application of observations to the entirety of Aleutian prehistory is problematic (e.g. Alix 2005).

## Chapter 6: Discussion

This chapter integrates the results of the otolith analysis and radiocarbon dates in a discussion of Pacific cod $\delta^{18}O_{otolith}$ values, site chronology, and Pacific cod harvesting in the western Aleutians in general, with a specific discussion of material at Gertrude Cove. Additionally, this discussion concludes with an assessment of the contribution of this study to the palaeoclimate record of the region.

The lack of clear otolith $\delta^{18}O$ values that may reflect sub-annual signals inhibits the identification of season of capture. This discussion outlines the complexity of identifying seasonality based on Pacific cod otoliths, and it is argued that Pacific cod presence cannot be used as a reliable indicator of summer occupation. The main limitation of this study is the sample size, and the future inclusion of geographically comparative archaeological and modern samples has significant potential to further interpret this data. Additional samples will also contribute to the development of modern and archaeological climatic and Pacific cod datasets in the western Aleutians, which are currently lacking.

The integration of otolith and climatic data with the radiocarbon dates obtained from Gertrude Cove illustrates a strong correlation between changing climatic regimes and the pattern of occupation at the site. This addresses a major theme in Aleutian prehistory and adds to the current understanding of the archaeological record of Kiska Island. The continued zooarchaeological analysis of the faunal material recovered from Witchcraft Point and Gertrude Cove has the potential to address a variety of regional knowledge gaps, as well as contribute to wider understandings of changing subsistence patterns and the interactions between the human inhabitants of the archipelago and their marine resources.

### 6.1 Pacific Cod Discussion

The Pacific cod $\delta^{18}O_{otolith}$ dataset demonstrates a weak pattern of inter-seasonal variation and minimal overall variation in ambient water conditions. Initial lower hatch values are followed by a spike at first winter. Up to year 3 a weak seasonal signal is identifiable, with $\delta^{18}O$ peaks corresponding to winter temperature lows. After year 3, values are relatively stable and do not demonstrate a clear cyclical seasonal pattern, which is followed by a gradual increase around year 6/7 that continues towards the margin. The mean values are presented below in Figure 5.8 and all $\delta^{18}O$ values are displayed in Figure 5.9.

The discussion here is focused on comparative otolith data, and is integrated into the palaeoclimate and archaeological records in section 6.7. The clustered range of the $\delta^{18}O$ archaeological Pacific cod otolith values indicates that the fish were exposed to minimal variation in ambient water conditions (e.g. small geographical range, minimal movement in the water column), and are potentially representative of a single breeding stock expressing high site fidelity (Gao et al. 2005; Helser and McKay 2013). Otolith K09 demonstrates the values with the smallest range (0.44‰), and otolith K17 is the most dispersed with a range of 1.03‰. Based on available comparative Pacific cod $\delta^{18}O$ data, as presented in Table 6.1, these values are relatively high, lack clear seasonal signals and ontogenetic indicators, and demonstrate a small range. Overall, the range of values is similar to that presented by Helser and McKay (2013), but significantly more clustered than the Puget Sound Pacific cod investigated by Gao et al. (2005). West et al.'s (2012) Kodiak Island otolith assemblage is the only available archaeological comparison, and

their data range is much narrower, but is based on averaged transects throughout the otolith as opposed to discrete data points.

**Table 6.1. Comparative $\delta^{18}O_{otolith}$ Pacific cod datasets**

| Data Source | Low (‰) | | | High (‰) | | | Range (‰) | | |
|---|---|---|---|---|---|---|---|---|---|
| This research | +1.70 | | | +3.01 | | | 1.31 | | |
| Gao et al. 2005 (Nuclei) | -1.4* | 0 | -0.8 | +0.5 | +1.4 | +0.5 | 1.9 | 1.4 | 1.3 |
| Gao et al. 2005 | -1.5 | | +0.5 | 1.5 | | 2.0 | 3.5 | | |
| West et al 2012 | +0.78 | | | +1.48 | | | 0.7 | | |
| Helser and McKay 2013 | ~0 | | | ~2 | | | ~2 | | |

*Note: Subdivided columns represent distinct geographical groupings identified by Gao et al. 2005

Core (1S) values range from +1.89 to +2.30‰ with an average of 2.01‰, and a highly clustered range of 0.41‰. Gao et al.'s (2005:338) values for otolith nuclei ranged from -1.4 to +1.4‰ depending on cod location and stock, while core values in Helser eand McKay's (2013) study average ~0.0‰. Three of the seven otoliths studied here demonstrate a substantial shift in $\delta^{18}O$ within the first year, which is also seen in some of the otoliths investigated by Helser and McKay (2013). This variation between hatch and first winter growth illustrates the highest variation in ambient water conditions in this study.

Following this initial variation, is a seasonal variation up to year 3 for all otoliths with available core values. As identified by Helser and McKay (2013), these peaks correspond to winter temperature lows. However, this seasonal variation is not visible after year 3; after this point the cod demonstrate minimal variation in ambient water conditions for the duration of their life. Edge values for five of the six otoliths with available edge data are high, indicating the cod experienced unprecedented cold ambient

water conditions prior to capture. These high margin values are further discussed below. A clear cyclical seasonal pattern cannot be identified here, and season of capture cannot be confidently estimated. The addition of further comparative Pacific cod otolith data will allow for an increased understanding of the lack of seasonal signals visible here. Integration with other known data sources (e.g. Pacific cod behaviour, western Aleutian oceanography) provides additional insight into this distribution pattern, and further demonstrates the value of expanding existing archaeological and modern cod $\delta^{18}O$ datasets.

Relatively little is understood about the specifics of Pacific cod behaviour and there is a significant knowledge gap concerning stock structure and movement, especially in the western Aleutians (Hurst et al. 2012:164; Ormseth et al. 2008). This is not restricted to this particular species, and the ecology of all demersal fish of the Aleutians is poorly understood; until further ecosystems analyses are completed we are reliant on generalized summaries applied to the region (Logerwell et al. 2005:94). Generally, Pacific cod demonstrate an annular cycle of seasonal migration from over-wintering spawning areas to warmer inshore waters for feeding until late September when the cycle is repeated (Shimada and Kimura 1994). During the summer feeding periods cod remain on the continental shelf up to 100 m, then move to the outer shelf (100-200 m) in the fall, before aggregating at over winter spawning zones off the continental shelf at depths over 200 m, (Davis and Ottmar 2009:30; Shimada and Kimura 1994; Spies 2012:1559).The stimulus for this migration appears to be avoidance of intense cooling or warming of inshore waters in preference for the more stable temperatures of deeper water (Shimada and Kimura 1994:814).

Cod express high spawning and feeding site fidelity, and although there is potential for long distance migration there appears to be minimal inter-stock movement (Berger et al. 2007; Shi et al. 2007; Shimada and Kimura 1994). Genetic studies suggest a range of around 30 km, while tagging studies suggest a range of 80 km, with migration and movement mainly occurring based on bathymetric conditions from inshore to offshore locations as opposed to by latitude (Cunningham et al. 2009; Shi et al. 2007; Shimada and Kimura 1994:814). The vertical distribution of cod in the water column is more limited and the range is controlled by various factors including age, feeding, reproductive state, and adaptation to changing conditions. In addition, environmental factors such as tide patterns, salinity, and oxygen also play a role (Davis and Ottmar 2009:34).

Cod larvae rise to the surface after hatch, with transport from spawning grounds, and other movement regulated by water currents (Cunningham et al. 2009; Hurst et al. 2012:164). Juvenile (year 0) cod then generally remain within kelp and eelgrass communities in near shore environments. However, they are not restricted to this environment, and recent studies have shown that juveniles are captured across the shelf in both demersal and pelagic trawls (Berger et al. 2007:1899; Hurst et al. 2012:164). As the cod grows to the age of sexual maturity, movement becomes directed by feeding, spawning activities, and water conditions.

The development of more consistent, attenuated $\delta^{18}O_{otolith}$ values is strongly correlated to fish maturity (Gao et al. 2005; Høie et al. 2004). This stabilization in $\delta^{18}O$ values is a reflection of the minimal movement of adult cod within the water column, combined with the species' demonstrated preference for stable water chemistry; however,

it is also due to the diminution of growth bands, especially winter growth, and the resultant sampling issues (Gao et al. 2001; Helser and McKay 2013). As cod age, growth and aragonite deposition mainly occur during the summer, providing an accurate $\delta^{18}O$ record of summer water conditions but not of winter conditions (Gao et al. 2001:451). However, these Kiska Island cod do not demonstrate a clear increase in attenuation at maturity, but relatively stable values occur immediately after the first year, and greater variability (less attenuation) occurs towards the margin. During the aging process it was noted that these archaeological Pacific cod had more clearly delineated annuli and were significantly easier to age than their modern counterparts (Chris Johnston, personal communication 2013), which may have prevented marginal attenuation.

Although a clear pattern of inter-seasonal cyclical variation is not expected for older cod, the overall lack of visible seasonal signals with these otoliths indicates possible sampling issues, a lack of fish mobility or tight geographical range, and/or a lack of variation between inter-seasonal water temperatures. Potential sampling issues are further discussed in section 6.4. From what is understood about cod behaviour, as discussed above, the cod most likely maintained a pattern of seasonal migration, although it may have varied from the pattern observed in other cod populations. The lack of representation in the $\delta^{18}O$ record indicates that either there was minimal variation in water temperature throughout this seasonal migration or other environmental and/or physiological factors are obscuring the seasonal pattern in the cod $\delta^{18}O$ values.

Regardless, similar to their modern counterparts, these Pacific cod from approximately 2500 to 500 years ago demonstrate their preference for consistent ambient water temperatures, which is potentially expressed through limited mobility. Non-

migratory or resident cod stocks have been identified in the Atlantic, where the cod maintain a highly localized habitat range. Although this has not yet been identified for the North Pacific, there is a possibility of more localized, non-migratory stocks, which could occur at locations of minimal seasonal ambient water variation (Cunningham 2009; Jamieson et al. 2004).

The major shift reflected in cod $\delta^{18}O_{otolith}$ is ontogenetic, representing the shift from juvenile to prematuration and maturation, as cod move from near shore more estuarine conditions to offshore environments (Gao et al. 2005; Helser and McKay 2013; Jamieson 2001). Age of maturity has been identified for Pacific cod at two to three years, with males most commonly reaching maturity at two years and females at three years of age (Gao et al. 2005; Hart 1988). Despite some indicators of this ontogenetic shift, it is not clearly indicated here as is expected for cod $\delta^{18}O_{otolith,}$ but is obscured by the clustered and enriched nature of the values (e.g. Gao et al. 2005; Jamieson 2001). Again, this could be a result of sampling issues, and a higher resolution analysis of the first two years of the cod's life would further clarify this. However, this could also be specific to the conditions of the western Aleutians, and a further comparison to modern western Aleutian Pacific cod would be valuable to identify any additional patterns.

Five of the seven otoliths demonstrate peaks in $\delta^{18}O$ values that correspond to winter growth bands for the first 2-3 years, followed by variable, inconsistent $\delta^{18}O$highs for the remainder of the fish's life. Although there is a lack of a clear ontogenetic shift, the seasonal signals identifiable up to year 2-3 become obscured after this age, which correlates to the age of expected habitat and dietary shift related to maturity. The cyclical variability prior to maturity most likely becomes obscured as the cod makes the shift into

deeper offshore waters. The juvenile cod, living in nearshore environments, would be more susceptible to changes in water temperature than the mature cod living offshore making limited excursions in the water column. As an age validation technique, Helser and Kastelle (2014; Helser and McKay 2013; Kastelle et al. 2012) have successfully demonstrated that peaks in $\delta^{18}O$ values are representative of low winter temperatures (i.e. winter growth bands) for Pacific cod aged 2-5. As with this assemblage, Helser and McKay (2013) also identify that this correlation becomes weaker as the cod ages. Higher resolution analyses (Secondary Ion Mass Spectrometry), as that completed by Helser and McKay (2013), has the potential to further refine these peak correlations with archaeological Pacific cod otoliths.

The overall limited understanding of the specifics of Pacific cod behaviour also manifests in the lack of clearly identified stocks. Stock structure is an integral component of marine resource management today, and currently all Pacific cod from the Aleutians and Bering Sea are managed as one unit (BSAI), but research is beginning to emphasize the presence of different stocks within this region (Spies 2012). Genetic data is lacking for the main commercial Pacific groundfish species and what is available has not successfully differentiated between stocks, as a result stable isotope analysis has recently been emphasized as a means to identify stocks (e.g. Gao et al. 2010). As one of the largest commercial fisheries, and the second largest U.S. ground fishery, developing a clearer understanding of Pacific cod stock structure is integral to sustainable management, and a main objective is to better link units of management to biological populations (Spies 2012:1558; e.g. Jones and Campana 2009). Additionally, with the recent collapse of nearly every major world fishery and the growing discussion of lack of past data to

inform current management strategies (the shifting baseline syndrome), archaeological data have the potential to add time depth to these valuable discussions (Erlandson and Rick 2008).

The collection of Kiska Island $\delta^{18}O_{otolith}$, assumed to be representative of localized western Aleutian Pacific cod, is characterized by the narrow range of values and relative uniformity across all otoliths. In comparison to other Pacific cod stocks currently being identified, the difference in absolute values combined with the relatively narrow range of values, is an isotopic stock indicator, based on patterns of migration, and exposure to similar ambient water conditions. The narrow range of these values is indicative of a single (non-mixed) breeding stock (Gao et al. 2005 :338), which is significant because individual breeding stocks within the western Aleutians have not yet been identified, and research is ongoing to delineate stock structures and better match these to management units (Ormseth et al. 2008).

Recent studies of the Aleutian passes have identified these areas as major barriers to population connectivity, and they act as ecological dividers (e.g. Hunt and Stabeno 2005; Logerwell et al. 2005). In addition to Unimak Pass, Amchitka Pass was also identified as a regional divide in spawning groups (Spies 2012). Samalga Pass in the central Aleutians (169°W), has also been identified as a climatological and ecological divider with substantial variation in climate and marine ecosystems east and west of the pass, which has led to arguments for the reorganization of fisheries management units (Hunt and Stabeno 2005). For example, a major shift in the diet of Pacific cod is identifiable west of Samalga Pass (Logerwell et al. 2005:105). Additionally, the scope of variation at this pass and the attention it has been given there are indications that this pass

may be only one of many dividers, especially throughout the deep passes of the western Aleutians (Hunt and Stabeno 2005). This further necessitates the addition of local (western Aleutian) comparative data.

There is little indication of inter-stock movement for Pacific cod, providing that cod harvested from a specific location would be of the same stock (Berger et al. 2007:1899; Gao 2010, Thompson and Dorn 2003). This Kiska Island assemblage supports minimal inter-stock movement as argued by Berger et al. (2007), and has the potential to add time depth to stock structure analyses, as the values are isotopic indicators of a single non-mixed breeding stock (Gao et al. 2005, 2010).

In conclusion, it has been demonstrated that the specifics of modern Pacific cod behaviour and habitat are relatively unknown and still being investigated, which is particularly true for western Aleutian cod. As a result, although our assemblage is small and lacks location and other data that could contribute to the discussion of behavioural patterns, there are potential indicators within this assemblage. Although the attenuation in values could be partly due to an inherent bias in sampling methodology, this indicates that the spawning habitat and feeding habitat have minimal ambient water differentiation, indicating similarities in water temperature and chemistry for both habitats. This assemblage also demonstrates minimal variation from juvenile to mature cod, which is not in agreement with other research on modern cod where greater variation is generally expected. This indicates a need for finer resolution sampling to explore this potential lack of represented habitat variation, and to further determine if this is a sampling, environmental, or behavioural issue. From a methodological standpoint, Secondary Ion Mass Spectrometry (SIMS) provides the next step in developing a higher resolution data

set and would significantly address these main questions (Helser and Kastelle 2014, Matta et al. 2013). However, the lack of variation is also in agreement with cod's demonstrated preference for stable water conditions, and potentially indicates that the cod had significantly minimal movement within the water column, perhaps represented by a stable depth within the water column from season to season after maturity. The seasonal migration round from deep spawning areas to shallower feeding areas is poorly understood in the North Pacific, and this assemblage highlights the need for further investigation into this seasonal migratory round.

### 6.1.1 Pacific Cod $\delta^{13}C$ Comparative Analysis

The main focus of this study was the $\delta^{18}O$ values, however the $\delta^{13}C$ values are addressed briefly here and integrated with known cod data. The precipitation of $\delta^{13}C$ is more complex than that of $\delta^{18}O$, with more contributing factors related to metabolic rates and feeding patterns (Høie et al. 2004:1039). Unlike oxygen, carbon does not exist in equilibrium with ambient water, and is instead metabolically regulated, with values representing a mixture of both ambient and dietary carbon (Jamieson et al. 2004:84). Characteristically, $\delta^{13}C_{otolith}$ values are significantly lower in comparison to ambient water, limiting the usefulness of $\delta^{13}C$ as a proxy for ambient water conditions, as it acts more of a record of physiological processes (Thorrold et al. 1997:2910). As a result, variation in $\delta^{13}C$ is representative of various factors (age, trophic level, temperature, and depth), with diet identified as the main influence on cod $\delta^{13}C$ (Jamieson et al. 2004). Although this limits the usefulness of $\delta^{13}C$ as an archaeological environmental proxy, it provides potential behavioural indicators. Most successfully, $\delta^{13}C_{otolith}$ have been

demonstrated to reflect the dietary shift in cod from movement to higher trophic level foods, and the $\delta^{13}C$ maxima can be an indicator of the age of cod maturity (Gao et al. 2005; Jamieson et al. 2004; Schwarcz et al. 1998).

The Gertrude Cove cod $\delta^{13}C_{otolith}$ generally display a pattern of low initial values followed by a spike within the first year, and subsequent low values again at the second summer. For two otoliths (K-09, K-17), this is followed by a stabilization of values at around year 3/4, as identified in the Puget Sound otolith assemblage investigated by Gao et al. (2005). In contrast, other otoliths demonstrate a continuous decrease in values (K-08, K-20), and others (K-01, K-02, K-12) irregular patterns, illustrating the variability either in diet or environment between individual fish. This variability in $\delta^{13}C$ values between fish has been identified in other studies of cod from the same stock (Jamieson et al. 2004 for Atlantic cod). Maximum values occur between year 2 and edge values, averaging a 2W-3W maxima, and range from -0.80 to -0.03‰; Figure 6.1 illustrates the mean $\delta^{13}C$ values.

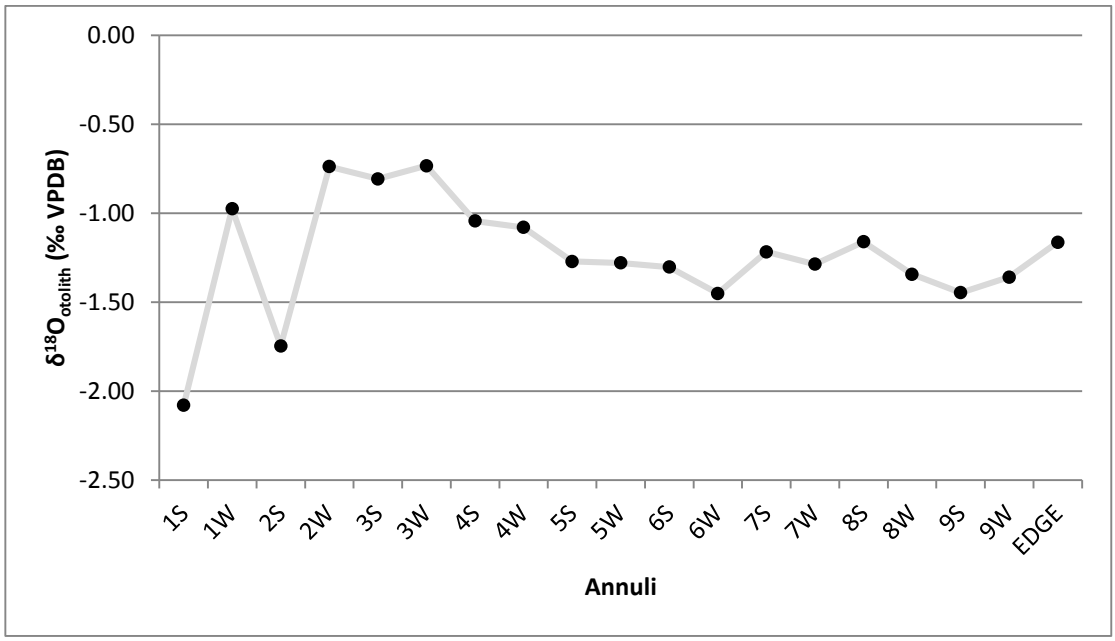



**Figure 6.1: $\delta^{13}C$ values of Kiska Island archaeological Pacific cod otoliths by annunli**[9]

As Gao et al. (2005:343) demonstrate, the age of fish maturity for Pacific cod can be inferred from $\delta^{13}C$ maxima, which is the critical age to capture the change in maturity and movement from estuarine or nearshore conditions to the open ocean. The authors identify the age of maturity for their collection of North Puget Sound Pacific cod as year 2. This identification of $\delta^{13}C$ maxima as a signature of maturity was previously identified by Schwarcz et al. (1998) for Atlantic cod, but Jamieson et al. (2004) identified fish length (35 cm) as opposed to maturity as the significant factor related to $\delta^{13}C$ maxima. Based on $\delta^{13}C$ maxima, the inferred age of maturity for this assemblage of Pacific cod can also be estimated at 2-3 years of age. Three otoliths have maximum values indicating maturity from 2W-3W. Of the remaining four otoliths, two otoliths have the 2W-3W range within 0.03‰ of the maxima, and the remaining two within 0.18‰ of the maxima.

[9] Only annuli with two or more values used for mean; one edge value outlier not included in calculation.

There is limited available comparative Pacific cod $\delta^{13}C$ data, and Gao et al. (2005) provide the only available comparison used here. The Puget sound Pacific cod $\delta^{13}C$ values range from -2.5 to 0‰, with a range of -2.5 to -2.0‰ at year1 and then a relative stabilization past maturity at -1 to 0‰ (Gao et al. 2005). Other North Pacific species demonstrate highly variable absolute values in comparison to Pacific cod, as would be expected due to dietary, habitat, and behavioural differences (e.g. Gao et al. 2010).

Studies of Atlantic cod demonstrate an overall increase in $\delta^{13}C$ values over the fish's lifetime without cyclical seasonal variation for adults (Jamieson et al. 2004). Similar to the Gertrude Cove Pacific cod values, the Atlantic cod in Jamieson et al.'s (2004) study also demonstrate depleted initial values, followed by a spike before stabilization later in life. The highest variability in both Jamieson et al.'s (2004) analysis and the data in this study is identifiable within the first 2-4 years, followed by stabilization over time. This pattern excludes otolith K02, which remains irregular. Overall, most otoliths show a relative increase in $\delta^{13}C$ values combined with stability or attenuation throughout the fish's life, except for otoliths K12 and K08, which both decrease throughout the fish's life. Jamieson et al. (2004) argue that the anomalous otoliths with depleted $\delta^{13}C$ values are representative of fish who consistently inhabited deeper waters with lower dissolved inorganic carbon. The authors support this with the capture data for the anomalous fish at a depth of 900 m, which is significantly deeper than the depth inhabited by the other sampled fish from that study. This seems especially applicable to otolith K-08 (Figure 6.2), due to the regular patterned decrease in values over time.

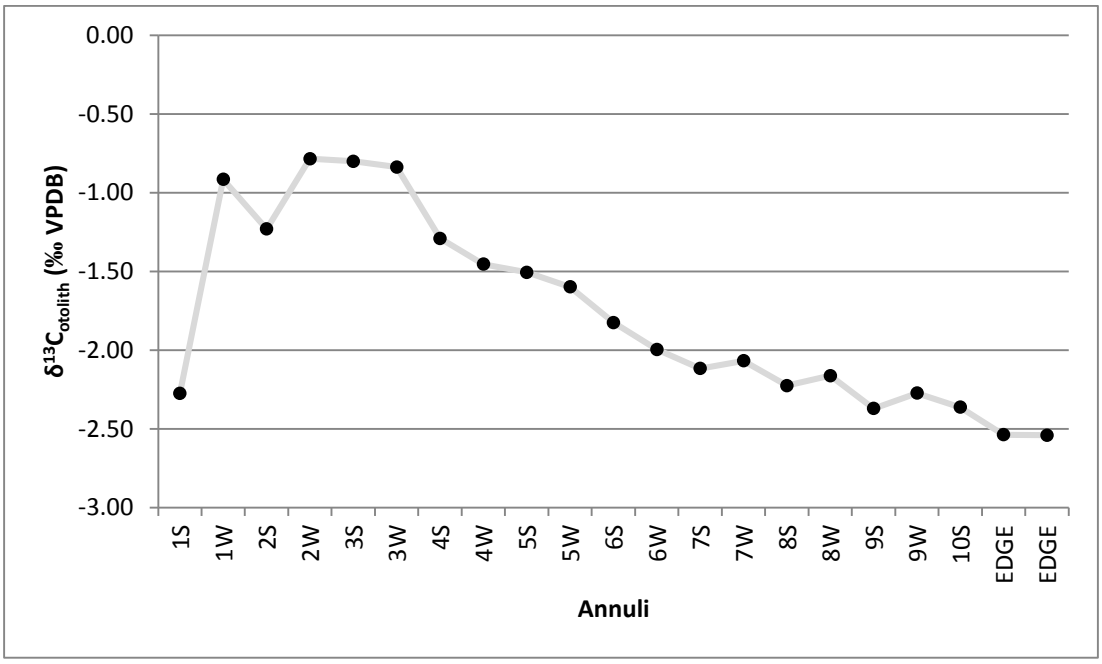



**Figure 6.2: $\delta^{13}C$ values of Kiska Island archaeological Pacific cod otolith K-08**

Even with identifiable similarities in overall $\delta^{13}C$ distributions, there is consistent variation between individual cod. This variation has been identified in cod from the same stock captured at the same location, which is arguably due to individual diet preference and differences in metabolism (Jamieson et al. 2004:94). Therefore, more consistent $\delta^{13}C$ values between cod cannot necessarily be expected. As Jamieson et al. (2004:95) point out for modern cod species, further isotope data is necessary for prey and ambient carbon at various water depths in order to better understand cod $\delta^{13}C_{otolith}$ distributions, a point which is amplified for archaeological samples.

### 6.2 Ambient Water Conditions and Season of Capture

Pacific cod have a notably small temperature range and a proven preference for stable water chemistry, and the maximum lifetime temperature range for Pacific cod is

approximately 6°C (Alaska Department of Fish and Game [ADFG]1985:321-322). This is seen in this study with the $\delta^{18}O$ demonstrating a maximum inter-seasonal variation of 4.91°C, and a total maximum variation of 6.25°C, spanning the ~2000 years of site occupation represented by the otoliths. Individual otolith inter-seasonal variation ranges from a maximum 2.07°C to 4.91°C throughout the cod's life, with an average inter-seasonal variation of 0.71°C, and an average total variation of 3.71°C per otolith. The minimum water temperatures occur at the first and second winters, as well as at the margin. Edge values range from 2.49 to 3.01‰, representing a temperature range of 2.48°C between all edge values. These marginal values are an average 0.5‰ higher than non-margin values, indicating edge values represent water temperatures ~2.4°C colder than total average $\delta^{18}O$ values.

In general, Pacific cod demonstrate a preference for temperatures ranging from 2.5 to 8.5°C for egg survival and spawning probably does not occur outside 0-9°C; in the western Bering Sea spawning occurs between 0-3°C (ADFG 1985:321-322). In the eastern Bering Sea mass winter aggregations of Pacific cod occur at areas of relatively warm and more stable water at approximately 4°C, which is maintained year round in the depths off Unimak Pass (Shimada and Kimura 1994:814). Bottom temperatures on the shelf in this area ranges from 0.2 to 4.5°C in the summer and drop below 0°C in the winter; in the Gulf of Alaska, spawning site temperatures sit at around 5.4°C at depths of 150-250 m (Shimada and Kimura 1994).

Today, Northwest Pacific Ocean and Bering Sea surface temperatures (SST) are characterized by strong seasonal variation, with winter temperature ranges of 0-2°C and summer ranges of 8-10°C (Max et al. 2012:3). This surface variation is followed by a

severe drop in temperature to ~2°C within the first 120 m from the surface, and from approximately 120-400 m there is minimal variation in temperature (~2-4°C) (Riethdorf et al. 2013). The strong variability in surface temperature, combined with the wide range in temperatures between strata in the water column, and the average 2°C range in water temperature from 120 to 400 m indicates that the cod most likely inhabited this lower strata in the water column. The fish likely made minimal movement towards the top 120 m of the water column where temperature varies substantially, especially in close proximity to the surface. This is supported by recent trawl survey research that indicates cod towards the western Aleutian Islands were caught at a depth range of approximately 100-200 m (Logerwell et al. 2005:104).

The Aleutian archipelago also has significantly more complex bathymetric and hydropgraphic conditions than the Bering Sea, and the increased complexity of conditions at the island passes remains beyond current understanding. Recent investigations of these ocean passes provide more detailed hydrographic data for the study region, and also serve to acknowledge the oceanographic complexity, especially at these passes (Hunt and Stabeno 2005; Ladd et al 2005; Logerwell et al. 2005; Stabeno et al. 2005). The main ocean passes influencing the study area are Amchitka Pass (depth 1155 m) and Buldir Pass (640 m), as well as the smaller Kiska Pass (depth 105 m). Overall, analyses indicate that the bottom water conditions of the passes demonstrate annular variation in temperature but the deeper passes towards the western Aleutians are generally more stable with less variation (Stabeno et al. 2005). Bottom temperatures at the passes seem to vary annually by ~1.5°C, reaching seasonal maxima in September and minima in May (e.g. Tanaga Pass ~4 to 5.5°C). These studies also demonstrate the vital role the strong

tidal currents play in regulating salinity, temperature, and mixing within the water column (Stabeno et al. 2005:52).

Although water temperature has been clearly demonstrated as the dominant factor regulating $^{18}O$ uptake (Gao et al. 2001; Helser and Kastelle 2014), salinity also positively influences $\delta^{18}O_{otolith}$ values (Elsdon and Gillanders 2002). Further investigations into the role of salinity in $\delta^{18}O_{otolith}$ of Atlantic cod demonstrate that increases in salinity cause paralleled increases in $\delta^{18}O$, mostly related to ontogenetic shifts (Jamieson 2001). Since mature cod are expected to have limited movement within the water column they also are more likely to experience limited variation in salinity, resulting from glacial melt, freshwater, and seasonal variation (West et al. 2012:3281).

Gao et al. (2005) identified gradients of freshwater mixing in the $\delta^{18}O_{otolith}$ of their sampled cod from three different geographical locations ranging from the northern Puget Sound to the Washington Coast. The authors categorized the cod as either coastal or estuary, based on increased values resulting from degrees of freshwater mixing. This division is further confirmed by genetic studies that reflect this variation between estuarine and coastal cod populations (Cunningham et al. 2009). Following this, the $\delta^{18}O$ values of the Kiska Island cod are most similar to the coastal cod, but with further increased values indicative of less freshwater mixing than the Washington or inner coastal cod, which is expected based on their location (e.g. Gao et al. 2013). Additionally, recent studies have indicated that the division of the Aleutian archipelago at Samalga Pass (170°W) results in varied oceanographic conditions, and west of Samalga Pass is a much more saline environment due to dominating currents (Hunt and Stabeno 2005:295).

### 6.3 Season of Capture

The lack of a clear cyclical seasonal variation prohibits the identification of the season of capture. Microstructure analysis indicates that two otoliths (K17, K20) were harvested during cold water temperatures (translucent bands), and the remaining 5 during warm water temperatures (opaque bands). In contrast, isotope results for otoliths with usable edge values indicate that the fish were exposed to the coldest ambient water conditions closest to the time of capture. Edge values average 0.5‰ (n=6, ±0.27‰) higher and 2.4°C lower than average overall values. This indicates that the cod were harvested during exposure to cold water temperatures.

The high edge values indicate that at this period the fish were experiencing cold temperatures unprecedented since maturity. Since cod prefer stable temperatures, this implies a behavioural or environmental anomaly related to season of capture. It has been argued here that the lack of a cyclical seasonal variation past year 3 indicates that the cod remained within a stable, relatively deep (at least 100-200 m) environment with spawning and feeding occurring at relatively consistent depths, and a record of minimal excursions within the water column. Without a comparable seasonal cycle of variation throughout maturity, this increase in edge values indicates an increased mobility prior to capture, potentially represented by excursions in the water column previously unprecedented in the mature cod's life. However, the overall trend of enrichment in values over time, as opposed to clear seasonal fluctuations, may also indicate that other behavioural, environmental, or sampling methodology factors are influencing the $\delta^{18}O_{otolith}$ values, and that season of capture cannot be clearly determined from the microstructure and isotope

results. The sub-annual scale is identifiable, but the precise season of capture cannot be inferred.

Additional data, both archaeological and comparative modern analogs at a higher resolution, are required to further the interpretation and discussion of this data. However, based on the age of these cod and increasing evidence that adult Pacific cod do not demonstrate clear seasonal $\delta^{18}O$ values, determining season of capture will continue to be a challenge. Recent considerations of other seasonal indicators, such as strontium, may prove invaluable in this respect (Matta et al. 2013). However, there is extensive potential for both $\delta^{13}C$ and $\delta^{18}O$ signatures, as well as the otolith's role as an environmental recorder and indicator of past climatic conditions, to address both archaeological and modern fisheries and climate research gaps.

### 6.4 Methodological Considerations

This analysis demonstrates that the methodological approach to extracting environmental data from archaeological cod otoliths, as outlined in Chapter 4, is both feasible and has significant potential. However, this method is time consuming and requires collaboration to ensure accurate and representative results. Consequently, an ideal approach for the continuation of this research is as a component of a collaborative project to develop modern baselines and extract archaeological data that is applicable to both past and present discussions of cod and their ambient water conditions.

Due to the small sample size and the need for both modern and historical western Aleutian cod stable isotope baselines, this project provides a useful step, but further

analysis and integration is required. In terms of site analysis, this data cannot stand alone and must be integrated into other components of zooarchaeological and archaeological discussions for maximum interpretative value. The zooarchaeological analysis of the site still requires completion, limiting a wider zooarchaeological discussion of the representatives of the sampled otoliths.

The analytical method in this study, although well established in some research areas, requires technical training and support. The sample extraction is integral to acquiring reliable results and the subsequent interpretation. Most significantly, the potential for attenuation is highly possible due to the methodological approach, causing an increased clustering of values. Attenuation would be most expected towards the margin, as the bands become increasingly narrow. The modified sampling strategy employed to obtain edge values was developed specifically to address the potential for attenuation. The diminution of annular bands as the cod ages poses issues for micromilling, and clearer results can be expected from more experienced analysts. In addition, a skilled microstructure analyst is required to better highlight the banding, both at the margin, but also during the first year of the cod's life when irregular growth causes additional non-annular bands.

Until recently, micromilling has been the main means of extracting carbonate samples from otoliths and is widely employed in fisheries labs. However, higher resolution analyses are becoming more popular in research projects, and the potential of SIMS cannot be stressed enough (Helser and Kastelle 2014, Matta et al. 2013). Overall, the lack of clear seasonal minima and maxima, combined with enriched marginal values could be a methodological issue. The marginal values would lack this attenuation because

they were shaved from the outer margin towards the core, as opposed to outwards from the core, with the epoxy removed prior to sample collection.

The milling of additional otoliths in a microanalysis facility would allow for further investigation into the representativeness of these values. Additionally, further work with SIMS, even on one otolith, would be an ideal future progression of this study, allowing for a much higher resolution. Only recently has SIMS begun to be used to extract otolith oxygen isotope ratios (e.g. Matta et al. 2013; Helser and Kastelle 2014), and the National Oceanic and Atmospheric Administration [NOAA]'s Age and Growth program is beginning to analyze archaeological otoliths using SIMS (Helser and Kastelle 2014). One Pacific cod thin section from Gertrude Cove (K-01) has the potential for this analysis with NOAA and has been retained by Helser and Kastelle for this use, dependent on the progression of this project and funding availability. Another adaptation of the sampling methodology that could offer improvements and address attenuation issues is the extraction of multiple samples per annuli, following Høie et al. (2004). However, this would increase the cost of sampling, and consequently lower the overall number of otoliths and bands undergoing analysis. To further address potential methodological issues, multiple subsamples were taken of otolith edge material where feasible, and values are consistent (Figure 5.9).

To address these issues, the assistance of skilled otolith readers for Pacific and Atlantic samples, as well as available training and technical support at CREAIT's microanalysis facility, was acquired. Consultation with Stable Isotope Lab Co-Ordinators Drs. Alison Pye and Jennifer McKay, also provided substantial modification and improvement to sampling procedures. These collaborations and procedures were all

undertaken to address the potential for bias and sampling precision. Additionally, the attenuation seen with the Pacific cod otoliths is not seen in the Atlantic cod samples, which were sampled earlier in the project and were not subjected to surface polishing as the Pacific cod samples were, which made the annular bands more distinguishable. Therefore, although it is likely that some attenuation occurred as a result of sampling, which is expected, the procedures and efforts undertaken here minimized the potential for attenuation and other bias. Based on the clarity of the banding and the training and assistance with micromill sampling procedures, it is unlikely that sampling bias is the dominant factor causing attenuation, although it would have contributed to some degree and is unavoidable. This is especially true for the substantially larger bands for the first two years of the cod's life, which are easily micromilled without risk of contamination from adjacent bands, as well as edge annuli, which were shaved from the outer margin in consultation with NOAA Age and Growth personnel (Craig Kastelle, personal communication 2013). As well, the standardized attenuation across all otoliths, indicates that sampling is not a primary cause in attenuation, as discussed in the behavioural and environmental discussion in Sections 6.1 and 6.2.

An additional issue that was not anticipated was the transport and analysis of samples and issues with sample size. The minimum sample weights required for standard mass spectrometry (~100 µg) significantly hinder the analysis of individual otolith bands, which has played a role in sampling strategies in previous studies where multiple bands or transects are clumped in one sample as opposed to isolating individual bands (e.g. West et al. 2012) . As a result, collaboration with McKay of Oregon State University's Stable Isotope Lab, significantly contributed to this project and ultimately made the analysis

possible. McKay, in collaboration with Thomas Helser of NOAA, has specifically tuned the mass spectrometer to accept sample weights suitable for individual otolith bands (~20 µg). However, transport issues continue to be fine-tuned. Static tends to cause the loss of material during transport and the subsequent transfer of material into lab vials for analysis (Jennifer McKay personal communication 2013), and the submission of heavier samples requires time consuming subsampling and weighing procedures.

### 6.5 Site Chronology

Radiocarbon dates are presented in Tables 5.6 and 5.7 and Figure 5.19 and represent just over 2000 years of discontinuous occupation, indicating two and possibly three distinct settlement periods at Gertrude Cove. As outlined in Section 5.6, all samples were assumed to be driftwood. The assumption that there is minimal time lapse between tree death and use is problematic when using driftwood for radiocarbon dates. However, investigations into the time span of tree death and driftwood use have demonstrated that there is a negligible (e.g. 3-6 years) difference for radiometric dating (Dyke et al. 1996; Eggertsson 1994)[10].

Assuming driftwood is not locked in ice for an extended period of time, it remains buoyant for less than two years indicating that the period it is water bound is minimal, but the length of time it could remain available in protected bays of the Aleutian Islands is unknown (Dyke et al. 1996). Carbon dating of driftwood charcoal is widely used in the development of Aleutian chronologies, and is considered a reliable source, especially in

[10] In reference to Canadian Arctic

comparison to marine faunal material (Dumond and Griffin 2002). Although there is potential for bias in these Gertrude Cove dates due to the driftwood samples, the stratigraphic agreement between dates is consistent indicating that although the dates have the potential to be skewed by older driftwood samples they can be considered a reliable addition to the relatively limited western Aleutian chronology. Further work and chronological refinement is necessary, and as additional dates become available the pattern of occupation in the Rat Islands appears to be more localized than previously understood (Funk 2011:48).

In the Rat Island group a series of occupations and occupation gaps have been identified, and although these may partly be manufactured by lack of thorough archaeological investigation, researchers suggest the gaps could result from "sociopolitical events, subsistence shifts, or tectonic events" (Funk 2011:48). The earliest sites in the Rat Islands have been identified on Amchitka Island to 3800-2800 BC (~5750-4750 BP), followed by a 500-700 year gap, with another occupation presence at 2300-1800 BC (~4250-3750 BP) (Funk 2011:48[11]; Desautels et al. 1971:384[12]). The earliest sites (totalling 7 sites and various occupations across Rat and Amchitka Islands) are represented by deep level sites without a surface presence, unlike the more commonly identifiable midden sites such as Gertrude Cove (Funk 2011:48).

From approximately 500 BC to 700 AD (~2450-1250 BP) occupation is identified in all island groups, followed by a 250 year gap, and then continuous occupation from 1000 AD to the historic period (Funk 2011:48, Figure 2). The frequency of identified and

[11] All dates presented by Funk in BC/AD and converted here
[12] Not calibrated

dated sites from this time increases substantially, indicating greater archaeological visibility, higher populations, and possibly increased mobility (Funk 2011:48). The dates from Gertrude Cove slightly vary from Funk's (2011) observations, with occupation from a maximum 2704 to 2358 BP (754 to 408 BC), with a possible gap until ca. 1945 BP, followed by a large gap of approximately 1200 years until continuous occupation at ca. 650 BP (1300 AD). At neighbouring Buldir Island, there is approximately 1000 years of occupation, ranging from approximately 1160BP to 28 ± 50 BP (Corbett et al. 1997a:471). The dates provided here for Kiska Island correlate with known dates for the island and the region, and further extend the occupation of the island and greatly contribute to the refinement of the chronology of the island.

Although limited excavation continues to structure this record, the evident occupation clusters at Gertrude Cove are congruent with occupation clusters identifiable in known Kiska and Rat Island chronologies, with the second occupation cluster around approximately 500-600 BP and the earlier occupation evident around 2000 BP. The record of Amchitka varies from this emerging pattern for Kiska and Rat Island (see Funk 2011: Figure 2). A difference in occupation patterns is expected, partially due to the extensive excavations on Amchitka, which provide a more consistent record. As well, Amchitka is recognized historically as a population base in the Rat Islands, indicating the islands would have been populated and structured differently; however, the Rat Island population has been identified as highly mobile and shifting between islands and further work in the western end of the chain needs to be completed to have a better understanding of population (Black 1984; Funk 2011: Figure 2). Based on the parallel, but slightly

offset, dates between Kiska/Rat Island and Amchitka Island, the other islands in the group may have been occupied at ca.5200 BP.

Wider chronologies for the region generally begin with the Anangula Blade site (Anangula Island), at about 8000 BP, which marks the earliest human occupation in the archipelago (Corbett et al. 2008:46). As previously discussed, the archaeological record indicates that the first inhabitants arrived in the island chain with a maritime adaptation. The Aleutian Tradition of ca. 3000 BP is identified as the peak, characterized by a highly developed sea mammal hunting adaptation (Corbett et al. 2008:45; McCartney 1984:121-122). The Aleutian Tradition is further subdivided into the Amaknak (3000-1000 BP, in eastern Aleutians) and Late Aleutian Trait complex (1000-200 BP) (Corbett et al. 1997b; Funk 2010:7; Knecht and Davis 2001; 2008).

There are widespread cultural changes documented throughout the region at the onset of the Late Aleutian Trait complex ca.1000 BP. A second migration wave into the island chain occurs at this time, which is considered a component of a Pan-Alaskan cultural movement, and has also been correlated with a period of glacial advancement (Coltrain 2010; Corbett et al. 1997b:463; Funk 2010:7; West et al. 2007:49-50; West et al. 2010). This period is marked by identifiable cultural changes including: variation in tool kits, house structures, and mortuary practices (Coltrain et al. 2006:545; Davis and Knecht 2010; Knecht and Davis 2001; 2008). These are linked to changing economic strategies with different patterns of consumption, including a greater emphasis on larger marine mammal hunting, although this is mainly based on analyses in the eastern Aleutians (Coltrain 2010; Hatfield 2010).

At this time, ground slate and iron tools are also introduced and there is evidence of increased inter-island cultural identity and expression (Funk 2010:7; Black 1984:53, 56; Jochelson 1968:21-23[1933]). On nearby Amchitka at ca. 1000BP, there is clear evidence of the development of a distinctive assemblage, defined by bone tool technology, but also an increase in ground stone tools and the introduction of metal tools (Desautels et al. 1971:349). Iron becomes relatively common throughout the Rat Islands after approximately 1000 BP, assumedly sourced from Japanese and Chinese shipwrecks (Corbett et al. 1997a:467). As iron is rarely identified within assemblages from other island groups at this time, it appears that Rat Islanders either preferred iron or kept control over its access (Corbett et al. 1997a:467). No metal tools were recovered from Gertrude Cove; a number of groundstone blade fragments were recovered, and one nearly complete basalt ulu knife was recovered from Level 11 (ca. 550 BP) (Lech et al. 2012).

The occupation of Gertrude Cove spans both components of the Aleutian Tradition, with the potential to provide further insight into this shift at ca. 1000 BP. Although earlier studies assumed this second migration wave occurred as a population replacement (Hrdlička 1945), the two genetically and culturally distinct populations are now considered to have inhabited the island chain contemporaneously (Coltrain et al. 2006:545; Coltrain 2010). Based on the available dates for Gertrude Cove, there is a discontinuity in site occupation between these two populations, with evidence of a Paleo-Aleut occupation towards the beginning of the Aleutian Tradition. This is followed by a maximum ~1300 year absence, with subsequent continuous occupation during the latter half of the Late Aleutian Trait complex extending into the historic period. Further

investigation into the faunal and tool assemblage will provide a better context to discuss this gap, and aide in identifying and discussing the transition between these populations.

### 6.6 Pacific Cod Harvesting

Pacific cod are a dominant species within zooarchaeological assemblages in the Aleutians (West et al. 2011). Based on the number of individual specimens (NISP), of the otoliths recovered from Kiska Island there is a significant *Gadidae* (60%), and Pacific cod (24%) presence[13]. Other represented species potentially include: Saffron cod *(Eleginus gracilis),* Pacific tomcod (*Microgadus proximus),* and Walleye pollock *(Theragra chalcograma).* A full analysis of the recovered fish remains is required to inform any wider interpretations, and these values cannot be applied to subsistence interpretations. Generally, fish remains have not been a focal point of zooarchaeological analyses in the Aleutians, partly due to their volume and difficulty in assigning taxa, and bulk sampling strategies are often employed. This significantly impacts the availability of representative fish samples; as well, the bias against fish bone recovery and representation in zooarchaeological analyses in general is well documented (e.g. Whitridge 2001:28).

A full zooarchaeological analysis of the material is pending. A preliminary analysis indicates that Pacific cod and greenlings (*Hexagrammidae* spp.) dominate the assemblage (Lech et al. 2012:8). Further investigation will provide for discussions of subsistence patterns represented by the Gertrude Cove material, and will allow for the better integration of the otolith data.

[13] This is only for otoliths and cannot be considered as representative of the fish remains or the site, and is not valuable in interpreting subsistence patterns. A full zooarchaeological analysis is required.

Total fish length was inferred from well preserved otoliths; the lengths are considered rough estimates as archaeological otoliths cannot provide accurate lengths due to potential deterioration, as well as variation in growth patterns over time. Fish lengths range from 59.5 to 91.8 cm, with an average length of 71.3 cm. Age estimates for the Kiska Island cod range from 6 to 11 years, with a corresponding range in fish length of 60 to 83 cm. Overall, these lengths are similar to modern cod lengths and do not show substantial variation over time. A recent analysis of BSAI fisheries data indicates a range in Pacific cod length from 19 cm (year 1) to 89 cm (year 12) (Thompson and Dorn 2003:132). A collection of modern Pacific cod, caught by line and hook off Kiska Island, average about 47 cm in length, with larger cod (54-61 cm) caught from nearby islands (Berger et al. 2007:1901). However, the lengths inferred from the archaeological otoliths do not demonstrate a direct correlation between age and fish length, further demonstrating potential issues in estimating fish length from archaeological otoliths. Although these length estimates indicate the potential for some error, these cod appear to be comparable in size to their modern counterpart, which has also been demonstrated for historic Atlantic cod (Bolle et al. 2004). However, Betts et al. (2011) determined that for both Atlantic and Pacific cod, size varied on an interdecadal scale.

**Table 6.2. Pacific cod otolith length, fish length, and fish age**

| Otolith | Side | Fish Age | Otolith Length (mm) | Fish Length (cm) |
|---|---|---|---|---|
| K-01 | R | 11+ | 21.6 | 70 |
| K-08 | R | 9+ | 24.8 | 83 |
| K-17 | L | 9 | 20.8 | 67 |
| K-12 | L | 8+ | 21.8 | 71 |
| K-20 | L | 8 | 24.8 | 83 |
| K-02 | L | 7+ | 21.5 | 70 |

| | | | | |
|---|---|---|---|---|
| K-09 | R | 6+ | 19.1 | 60 |

This discussion focuses specifically on Pacific cod harvesting, and marine species harvesting in general, and freshwater species are not addressed. Due to the availability and dominance of marine resources there are limited discussions of freshwater species in the literature. However, it should be noted that today there is at least one substantial pink salmon (*Oncorhynchus gorbuscha*) stream on Kiska Island, which is at Gertrude Cove (Dinnocenzo 2003:2); as well, Funk (2011:46) preliminarily identified salmon remains in test pits on Kiska Island. However, despite the availability of salmon and trout (*Salvelinus malma*) on nearby Amchitka Island, no freshwater fish remains were identified at any archaeological site on the island (Desautels et al. 1971:320; Dinnocenzo 2003; U.S Fish and Wildlife 1988). Although the timing of the Aleutian salmon run is considered variable, it is generally between late July and September (Dinnocenzo 2003:2).

Consistent with the lack of extensive archaeological work in the region, there are limited available comparative zooarchaeological analyses of fish remains. A preliminary analysis of fish remains from Amchitka Island indicates the presence of halibut (*Hippoglossus stenolepis*), Pacific cod, rock greenling (*Hexagrammos lagocephalus*), red Irish lord (*Hemilepidotus hemilepidotu*s) and *Sebastodes* sp. (rock fish) (Desautels et al. 1971:318). Additionally, one Pacific cod otolith was identified. The authors suggest that there is a greater representation of fish species common to the near shore waters of Amchitka, specifically the greenling and Irish lord. The fisheries study of Amchitka, also conducted as a component of the environmental assessment prior to nuclear weapons testing, supports this and determined that these species (rock greenling and Irish lord)

were abundant in the intertidal zone (Desautels et al. 1971:320). According to the authors, cod can most easily be caught near shore in late winter (Desautels et al. 1971:320).

*Gadidae* spp., especially Pacific cod, dominate the assemblage of test unit bulk samples from neighbouring Rat Island (RAT081), with sculpins (*Cottidae* sp.), greenlings (*Hexagrammos* sp.), and Atka mackerel (*Pleurogrammus monopterygius)* also well represented (Funk 2011:39; Partlow 2008). The relative proportions of the different species did not vary over time, with evidence of cod preference throughout time except in the oldest occupation layers. Funk (2011:38) considers the faunal material to represent summer occupation, when fish species inhabiting inshore or nearshore environments provided increasing accessibility to site occupants, which is widely echoed by other researchers throughout the Aleutians.

To the west, at Buldir Island, avian remains dominate the zooarchaeological material, followed by mammals and fish (Lefèvre et al. 1997). Although the authors were only able to identify a small portion of fish remains to species, the assemblage is dominated by rock greenlings and other *Scorpaeniformes* spp., with Pacific cod and halibut only minimally represented (Lefèvre et al. 1997:121). Similar to Funk (2011), the authors point out that the fish remains support a summer occupation based on seasonal near shore availability (Lefèvre et al. 1997:125). An analysis of material recovered from a burial cave in the Near Islands indicates that fish represented less than 5% of overall fauna, 79% of which is identified as Pacific cod (West et al. 2003:83). Based on the represented marine species the authors suggest harvesting primarily occurred by offshore *baidarka* fishing, which below is argued as a mutli-season fishery.

To the east, an analysis of fauna from test excavations of a large village site on Adak Island (ADK-011) in the Central Aleutians indicates that fish represented 77% of the zooarchaeological assemblage; rock greenling and Pacific cod were the most common fish (Lefèvre et al. 2011:76, 78). Cod representation varied by excavation unit, from 64% of total fish remains to 27%. At the thoroughly studied Amaknak Bridge site in the eastern Aleutians (Unalaska Island), fish constituted 43% of the faunal assemblage, followed by birds and mammals. Of the fish remains, Pacific cod totalled 89% of individual specimens, followed by salmon (4%), and halibut (3%) (Knecht and Davis 2008:75). The authors argue that based on faunal material and fishing related artifacts, Pacific cod and halibut were caught during the summer when the fish were close to shore with hook and line technology (Knecht and Davis 2008:75). Cod are also the dominant fish remains at Ashishik Point on neighbouring Umnak Island. Denniston (1974) quantitatively ranked the role of represented species, and argues that cod was the third most significant harvest for the Ashishik inhabitants, after whale and sea lion (species not indicated). Denniston (1974) also identified variation over time, with sea mammals dominating until about 1500 AD, after which cod and sea mammals had relatively equal representation.

Overall, the role of fish in the *Unangan* diet appears to increase westward along the island chain paralleled by a decrease in sea mammal reliance (Lefèvre et al. 1997; Veltre 1998:228). Although uniformity in procurement patterns across the archipelago is stressed by some scholars (e.g. McCartney 1984), Black (1984:61) notes that fishing and hunting methods varied between island groups. However, interpretations remain reliant on somewhat generalized fishing methods for the region.

Numerous bone fish hooks and shanks (n=21) were recovered from Gertrude Cove and shown in Figure 6.3, which is congruent with the extensive amounts of fish remains recovered. All hooks and shanks are made of bone; hooks are primarily of bird clavicles and fish spines. Composite fish hooks are represented throughout all layers in the midden. Hooks range from 2 to 3 cm in length, which are relatively small compared to some collections (e.g. Betts et al. 2011:175) but comparable to those recovered from Amchitka (Desautels et al. 1971: Figure 110).

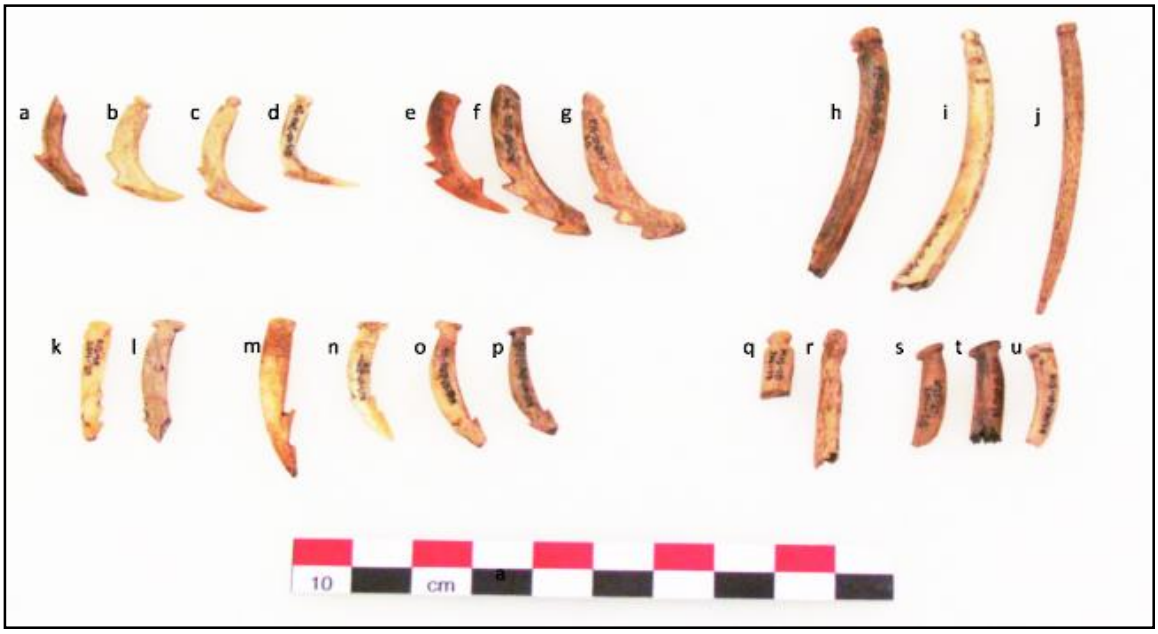



**Figure 6.3: Fish hooks and shanks recovered from Gertrude Cove. Photo by Veronica Lech**

Jochelson (2002:122[1925]) identifies a variation in fish harvesting tools over time, from fish spears in lower stratigraphic levels to the dominance of composite fish hooks in upper stratigraphy, which is not reflected in the Gertrude Cove assemblage. Based on the fish hooks (composite shank and hook) recovered from Amchitka Island (n=645), Desautels et al. (1971:207-211) developed a system of categorization based on a

variety of unique attributes, and were able to identify some variation over time. Based on this, the majority of fish hooks from Gertrude Cove fall into category A/B, but F/G types are also represented. These types are distinguished by angle of hook and the type of barb or notching. A major distinction between these types is that the F/G hook points were only found below 160 cm (Desautels et al. 1971:214). This stratigraphic divide is also identifiable in the Gertrude Cove assemblage, as the two hook points representing the F/G subtype were recovered at L27 (~380-390 cm) and L19 (~250-270 cm). Although not discussed by Desautels et al. (1971), the variation in hook types can also be considered species specific, and not representative of temporal developments. Hooks were designed for particular fish species and procurement styles (e.g. inshore/offshore) (Jochelson 1958[1933]:87). For example, small, one piece hooks were used for shallower water fishing, with larger composite hooks intended for offshore *baidarka* fishing (Jochelson 1968[1933]:87). Additionally as Betts et al. (2011:175) point out, both modern and archaeological fishing gear is specifically manufactured to target certain size ranges within a fish population.

There is a variety of evidence for both warm and cold season fishing. As discussed in Section 2.3, early Russian travellers in the region observed that the *Unangan* fished throughout the year, but primarily in summer (Tolstykh 1761cited in Hrdlička 1945:39, 90; Jochelson 1968 [1933]:11). Desautels et al. (1971:320) argue that Pacific cod are most available during late winter; they conclude that during summer there is evidence for heavier reliance on near shore fisheries, while offshore fishing for cod and halibut was commonly conducted during the winter months. This is in agreement with ethnographic evidence for southeastern Alaskan groups (Moss 2011). Jochelson (1968

11:[1933]) remarks that *baidarka* fishing up to 21 km (13 miles) offshore led to an abundance of halibut and cod, but in winter the *Unangan* travelled further offshore for the same species. This is echoed by a late 18th century Russian explorer: "in the depth of winter, by the feverest cold, they go [fishing] just as in summer." (von Staehlin 1774:29).

March is the peak spawning season for Pacific cod (Thompson and Dorn 2003:170), and modern commercial Pacific cod fisheries mostly occur during the winter months (Moss 2011:156). Today the highest commercial catches of Pacific cod in the Bering Sea and Aleutian Islands occur between January and April, with highest hook and line catches occurring in February-March, mostly at depths up to 200 m (Stone 2006:231). Ethnographic evidence from southeastern Alaska, in reference to *Tlingit* fisheries, indicates that peak cod fishing occurred during March-April concurrent with peak spawning in the region (Moss 2011:153).

Archaeologically, Pacific cod presence is often assumed to indicate a summer occupation in the Aleutians, and harvesting is considered to primarily occur during spring and summer when cod reputably move inshore (e.g. Funk 2011; Knecht and Davis 2008; Lefèvre 1997; West et al. 2012). Despite the somewhat conflicting evidence on the availability and seasonality of cod harvesting, a winter offshore cod fishery is probable. As West et al. (2011:80) point out, the presence of a variety of fish species, including cod, indicates that the *Unangan* were harvesting both near shore and pelagic species, and evidence for deep sea fisheries extends to at least 4000 BP in the eastern end of the island range (Workman and McCartney 1998:365; Laughlin and Marsh 1951). Based on the renowned adeptness and skill associated with *Unangan baidarka* manufacture and use, the level of skill required for the long distance travel undertaken in these vessels, as well

as for the procurement of large sea mammals and halibut (up to 600 pounds), off shore cod harvesting in inclement conditions seems probable (Sauer 1802:182). As a result, assigning site seasonality based on the presence of Pacific cod remains is unreliable.

Further work can contribute by delineating distinctive patterns of cold (winter and spring) and warm (summer and fall) fishing strategies, as has been completed for areas of the Atlantic (Carlson 1986; Moss 2011:151). Additionally, as Moss (2011:149) points out, despite the heavy representation of Pacific cod in North Pacific faunal assemblages, there is limited research into the wider role and significance of Pacific cod in the lives of the region's inhabitants. In comparison to the attention paid to salmon procurement, the role of Pacific cod is highly underrepresented in regional culture histories (Moss 2011).

In summary, the presence of halibut, and arguable year round availability of Pacific cod at Gertrude Cove, indicates the occurrence of offshore fishing, which is discussed above and well documented in the literature. Although accessibility undoubtedly increases based on the annual migration of cod, there is no evidence indicating that the fish would have been exclusively available during summer months. This widely held assumption requires revisiting if it continues to be used as evidence for seasonality as the result is an overwhelming bias for the identification of summer occupation. This discussion argues for the likelihood of a year round cod fishery, and further analyses of the faunal material will provide significant insight into seasonal procurement patterns at Gertrude Cove over time. Additionally, despite the difficulty in assigning seasonality based on the otolith analysis, continued work and the development of further Pacific cod isotope markers (e.g. Helser and Kastelle 2014), has the potential to further address this gap in identifying patterns of seasonal procurement.

### 6.7 Palaeoclimate Record

Developing local environmental proxies with tight temporal control is highly valuable for discussions of Late Holocene climatic conditions and the effects of climatic variability on marine resources and human subsistence patterns (West et al. 2011:31). As environmental recorders, otoliths act as local environmental proxies, and especially when coupled with temporally specific data retain valuable evidence of the interactions between fish populations, climate, and the human use of marine resources (Geffen et al. 2011:1081). However, the discussion above demonstrates some of the issues involved in interpreting and applying archaeological otolith data, and the addition of a comparative modern data set as well as the expansion of the current archaeological data set is the key to addressing these issues. Nonetheless, this data provides a valuable building block in further interpreting localized Late Holocene climate conditions in the western Aleutians and discussing the occupational periods of Gertrude Cove. As West et al. (2011:131) point out, due to the highly localized nature of climatic variation, and issues applying non-local data, the temporal and geographical specificity of otolith data has the potential to assist in developing the Late Holocene record in the region.

Marine productivity is strongly correlated to climatic conditions, and marine fauna is sensitive to a variety of factors, including salinity and temperature changes as small as 2°C, which has been demonstrated to influence the historic abundances of cod and salmon in the North Pacific (Black 1981:315; Maschner 2012:138). Today a distinctive characteristic of the Aleutian climate is its relative uniformity, with the highest variability occurring locally (Rodionov et al. 2005; Veltre 2012). The region's climate is strongly

regulated by atmospheric circulation and prevailing currents, and the Alaskan Stream, flowing along the shelf from Kodiak Island, is the western Aleutian's dominant current (Hunt and Stabeno 2005:295; Savinetsky et al. 2004:336). Modern conditions in the southern Bering Sea region demonstrate variable cold and warm periods, and changing climates influence current flow and direction, zooplanktaon, as well as fish populations, including Pacific cod; temperatures over the last decade and a half have ranged from an average -1.76 to 7-8°C (Stabeno et al. 2013:35). Specific localized climatological and direct meteorological and oceanographic data for the Aleutian Islands remains relatively scarce due in part to the logistical issues related to acquiring data in the region (Rodionov et al. 2005:3).

In this section the palaeoclimate data inferred from $\delta^{18}O_{otolith}$ is discussed and compared to relevant literature, and the Gertrude Cove radiocarbon dates are used to further situate the site's pattern of occupation within known climatic patterns. The addition of further archaeological, historic, and modern samples will greatly enhance this discussion and aide in determining the representativeness of these samples when applying them to infer climatic conditions. Overall the otoliths demonstrate relatively minimal variation in ambient water conditions over the span of the occupation of Gertrude Cove. For the ~2000 years represented by the otoliths, there is an overall maximum variation in $\delta^{18}O$ values of 1.31‰, representing a range of 6.25°C spanning the occupation of the site; based on inter-seasonal variation (sequential bands), there is a maximum span of 4.91°C. In comparison to modern data for example, since 1950 Bering Sea surface temperatures have increased by about 1.47°C, while water temperatures at depths of 50-200 m have cooled by about 0.7°C (Khen et al. 2013:110-111). In addition, the recent climatic

variation in arctic and subarctic zones is unprecedented compared to variation over the last two millennia and modern analogs are considered inadequate (Clegg and Sheng Hu 2010:928; Misarti et al. 2009)

As discussed above, the relatively compressed spread of the values is potentially influenced by sampling procedures, which may have caused increased attenuation and further analyses have the potential to address this. However, based on this variation the maximum range of 6.25°C spanning the site occupation is relatively insignificant to influence cod populations over this time span. Pacific cod's preference for stable water conditions is well demonstrated, and a maximum range within a cod's lifetime is approximately 6°C (ADFG 1985:321-322). Individual otolith inter-seasonal variation ranges from a maximum of 2.07°C to 4.91°C, indicating that the variation over the duration of site occupation is beyond the preference of variation exhibited by each individual fish. However, this range in values appears to be more influenced by ontogenetic variation than by climatic variation, as the minima are consistently represented by core values and the maxima by edge values. This indicates that this variation is more a reflection of the shift in cod habitat and behaviour, not of overall variations in climatic conditions.

Averaged $\delta^{18}O_{otolith}$ values by level and associated radiocarbon dates do not demonstrate a clear pattern of variation over time (i.e. discernible cold and warm periods) (Figures 6.4, 6.5, and 6.6; Table 6.3). Overall there is minimal variation, with two cold periods associated with recent occupation (L2) and early occupation (L26); however, the outlying warm period is also representative of early occupation (L26). The otoliths from Levels 5 and 10 (ca. to 539-346 cal BP) demonstrate highly clustered values, and the

otoliths from L26 (2492-2600 BP) demonstrate the highest variability. This illustrates the value of adding further samples as well as issues in interpretation and potentially high climatic variation during this period of occupation. The $\delta^{18}O$ values are presented for the two main occupational periods at Gertrude Cove in Figures 6.5 and 6.6.

**Table 6.3. Otolith age, season of capture, and associated dates**

| Otolith | Side | Fish Age | Season | Level | Date (cal BP) |
|---|---|---|---|---|---|
| K-08 | R | 9+ | Warm | 2* | 346-463 |
| K-09 | R | 6+ | Warm | 5 | 346-463 |
| K-12 | L | 8+ | Warm | 10 | 513-539 |
| K-17 | L | 9 | Cold | 10 | 513-539 |
| K-20 | L | 8 | Cold | 13 | 585-646 |
| K-01 | R | 11+ | Warm | 26* | 2492-2600 |
| K-02 | L | 7+ | Warm | 26* | 2492-2600 |

*Indicates level was not radiocarbon dated; dates are estimated from adjacent layers

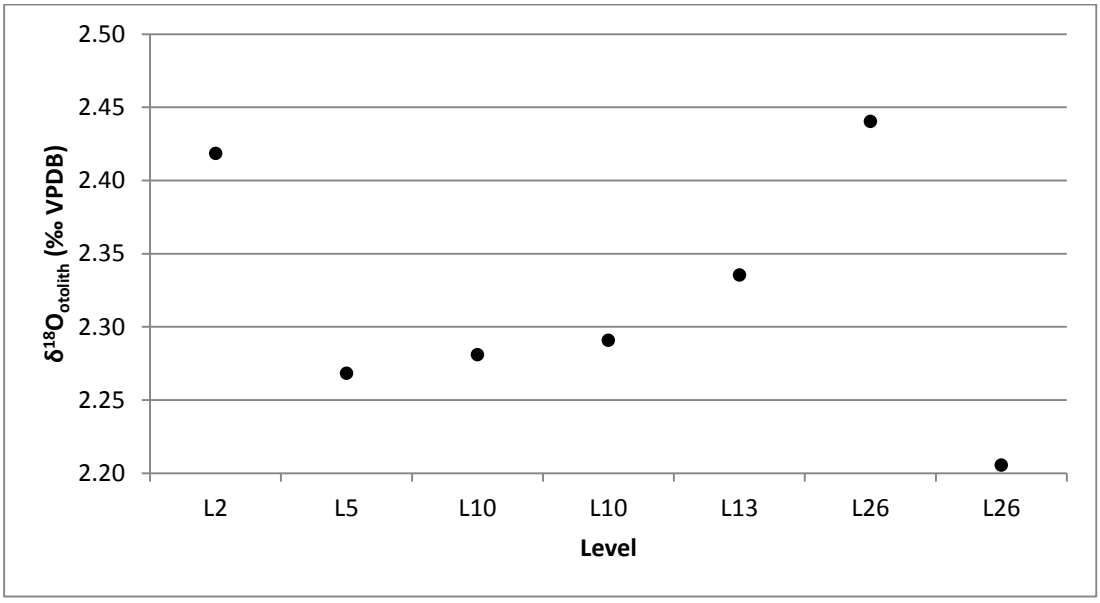



**Figure 6.4: Archaeological Pacific cod otolith $\delta^{18}O$ values by stratigraphic level at Gertrude Cove.**

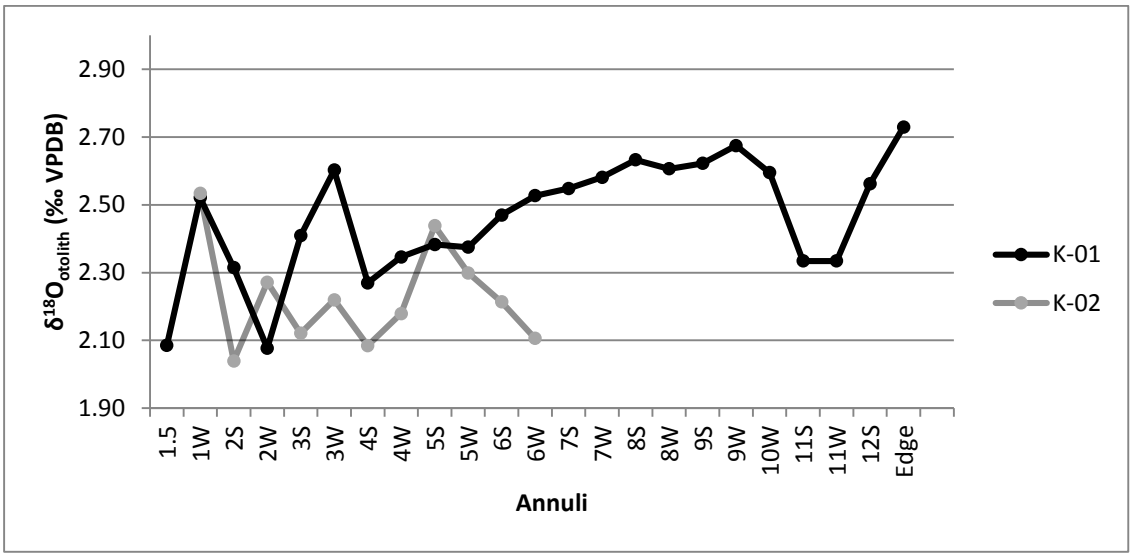



**Figure 6.5: Pacific cod otolith (K-01 and K-02) $\delta^{18}O$ values from the early occupational period at Gertrude Cove.**

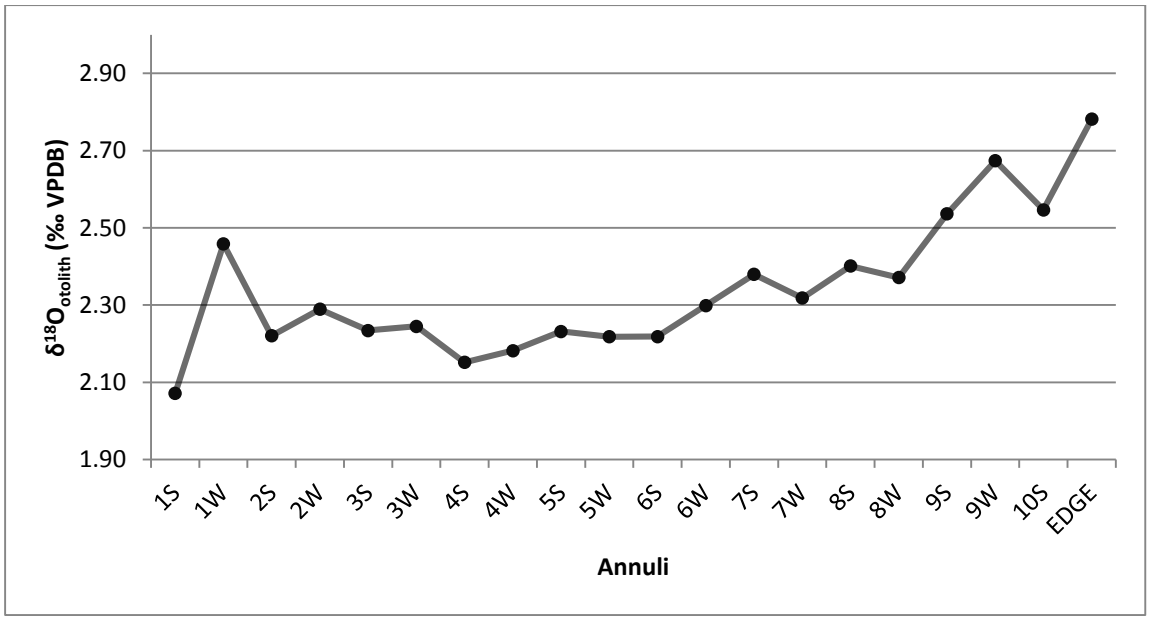



**Figure 6.6: Pacific cod $\delta^{18}O$ values for 346-646 cal BP occupation of Gertrude Cove.**

Overall, the $\delta^{18}O_{otolith}$ values for this Kiska Island assemblage illustrate variable water temperature at the onset of occupation (1°C variation), followed by a period of stable water temperature from maximum ca. 346 to 646 BP, with a subsequent decrease in temperature by about 0.7°C during the final occupation period at Gertrude Cove.

Although there are no dates available above L5 (346-463 cal BP), test pits completed at Gertrude Cove ranging from a maximum depth of 30-60 cm provide congruent and more recent dates (445-306 cal BP; 432-0 cal BP) (Funk 2011:27: Table 2). Additionally, a somewhat anomalous date of 169-224 cal BP was identified from L8 (Figure 5.19). Due to the small otolith sample size, this data set is highly vulnerable to variation expressed by individual cod, as the two samples from L26 further demonstrate.

In West et al.'s (2011:37) palaeoclimate study based on Kodiak Island otoliths, the authors isolate three periods with higher values that indicate colder temperatures: 530 BP, 320 BP, and post 130 BP. The authors also isolate a warming period at 390 BP. As discussed previously, West et al.'s (2011, 2012) sampling resolution differs from this study's as samples are aggregated and milled by transect, not by individual annuli. Similarly, for the Kiska Island otoliths, high values are also visible at the onset of occupation (L26) at 2492-2600 BP; the lowest value is also evident here, highlighting inter-otolith (individual fish) variability.

From approximately 4700 to 2500 BP there is evidence of a neoglacial cooling accompanied by sea ice expansion, the end of which roughly coincides with the initial occupation of Gertrude Cove at ca. 2704-2455 BP (Crockford and Frederick 2007). In general, periods of cooling, instability, and glacial advancement coincide with periods of heightened migration and movement in the Aleutians (West et al. 2010:51). The climatic data retained by the two otoliths from L26 represents the terminal period of this cooling; L26 was not directly dated, but based on adjacent layers (L25) is dated to approximately 2492-2600BP cal BP (or L28: 2358-2495 cal BP). This would account for the higher values of K-01 indicating colder temperatures, as well the variability between the two

otoliths (K-01, K-02) from this time period. These two otoliths are among the stratigraphically deepest, and assumed to be the oldest, recovered from the site. Compared to the total 39 otoliths recovered from the four test units at Gertrude Cove, six were recovered from Unit 2 Level 26 (~3.7-3.8 m dbd), and are all in good to excellent condition.

A localized (western Aleutian) cooling period has been identified from ca. 2100 to 1800 BP, followed by a warming period from 1100 to 650 BP with increased precipitation (Causey et al. 2005). This cooling period coincides with the final dates of the early occupation, or perhaps a minor secondary occupation at Gertrude Cove[14], represented by L20/21 at 1864-1945 BP (there were no otoliths recovered from these levels). The end of the ensuing warming period coincides with the re-occupation of the site at ca. 650 BP. The warming period identified by Causey et al. (2005) roughly coincides with the Medieval Warm Period (or little climatic optimum[15]) from 900-1350 AD (Mann et al. 1998); this is represented by a lack of dates, and inferred lack of occupation at Gertrude Cove, and also spans a period of major cultural shifts throughout the archipelago (Corbett et al. 1997b:463; Funk 2010:7; West et al. 2007:49-50; West et al. 2010).

The climatic conditions immediately following the warming period identified by Causey et al. (2005) are indicative of the most recent occupation at Gertrude Cove; therefore, the climatic data retained by the majority of the otoliths from L13 to L2 are representative of this post-warming period. This period coincides with the Little Ice Age

[14] Possibly a component of the original occupation cluster due to missing dates.
[15] 1100-800BP (Savinetsky 1995)

(LIA) from ~600-150 BP (ca. 1350-1800/1900 AD; Mann et al. 1998; Finney et al. 2002). Causey et al. (2005:260) identified climatic instability and a cooling period consistent with the time span of the LIA in the western Aleutians, indicating that the reoccupation of Gertrude Cove is consistent with a cooling trend, congruent with the LIA in the western Aleutians. Periods of cooler temperatures in the region are associated with an increase in marine productivity resulting from decreased temperatures and increased upwelling activities (Savinetsky et al. 2004:349). This is consistent with the occupational history of the neighbouring Near Islands, where original occupation occurs during the longest cooling period (West et al. 2007:52).

Causey et al.'s (2005) study is the most locally applicable palaeoclimate study and is based on the analysis of midden avifauna and associated environmental indicators from Amchitka, Buldir, and Shemya Island. Causey et al. (2005:259), identified that the region experienced high precipitation throughout the Holocene until ca. 5000 radiocarbon years before present (rcybp) when precipitation began to increase and eventually stabilized (ca. 2000 rcybp) at modern rates. From ca. 3000 to 2000 rcybp temperatures in the western Aleutians decreased significantly before stabilizing, with a ca. 250 year period of instability consistent with the LIA, and a warming period coinciding with Medieval Warm Period for Shemya Island ca. 900 to 1350 AD (Causey et al. 2005:260). However, the warming period in the western Aleutians is accompanied by a cooling trend for the eastern Aleutians, further demonstrating the localized nature of this climatic variation (Hunt and Stabeno 2005; Savinetsky et al. 2004).

Savinetsky et al.'s (2004) climatic reconstruction for the western Bering Sea, including data from the western Aleutians, demonstrates a negative correlation between

mammals and birds and air temperature (Savinetsky et al. 2004:349). An increase in productivity in the region is identifiable during periods of decreased temperature and resultant increased upwelling. In contrast, a positive correlation was identified with precipitation. The authors conclude that in the southern Bering Sea, the most dominant factor for bird and mammal populations over time was temperature regimes followed by precipitation (Savinetsky et al. 2004:349). Upwelling activity is characteristic of the Aleutians, and especially occurs at ocean passes where cold bottom water is pushed towards the surface creating nutrient rich areas that are highly productive (Black 1976). These areas are characterized by colder sea surface temperatures (SSTs) and increased salinity and nutrients (Sapozhnikov et al. 2010). A close association between archaeological site locations and major upwelling areas has also been well demonstrated (Black 1976; Yesner 1998:205).

The role of changing temperature regimes is integral to our understanding of the relationship between human inhabitants and their marine resources; however the interaction between changing climatic regimes and ecosystems is complex. Based on their study of variation in North Pacific salmon populations over the last two millennia, Finney et al. (2002:732) demonstrated that long term variation significantly differed from what is visible through historical records, highlighting that ecosystem relationships and climatic variation differ dependent on the time scale of investigation. Misarti et al.'s (2009) analysis of Pacific marine ecosystems over 4500 years highlights the complexity and dynamism of changing conditions, and indicates that modern variation is a poor analog for prehistoric conditions. The complexity of the relationships between marine ecosystems of the North Pacific are further compounded when human cultural change is

an added lens of investigation, and there is a strong link between climatic variability, human cultural change, and large scale human migration (Wurster and Patterson 2001:82). The potential for the evidence of interaction between these changing ecosystems and the human use, involvement, and response to these changes over time are clearly manifested in the archaeological record of the Aleutians. The complexities of which are highlighted in recent palaeoclimate investigations (e.g. Causey et al. 2005; Savinetsky et al. 2004), and the environmental data recorded by otoliths has the potential to contribute to the further evolution of these analyses but requires wider datasets and modern analogs.

In summary, despite a lack of comparable data, and the necessity for increased sampling, it appears that the distinct occupation periods of Gertrude Cove can be directly correlated to identifiable climatic trends, suggesting that changing climatic conditions are essential to understanding the occupational history of Kiska Island. More specifically, the site was first occupied (2704-2455 BP) at the end of the neoglacial cooling period at approximately 2500 BP, with evidence of either continuous or re-occupation corresponding with a localized cooling period from 2100 to 1800 BP. However, there is a lack of local data to indicate how the neoglacial manifested in the western Aleutians, and Hunt and Stabeno (2005) have argued the emerging division in modern climatic conditions between the eastern and western Aleutians likely extends into the past.

There is a lack of evidence for occupation at Gertrude Cove during the subsequent warming period from 1100 to 650 BP, with reoccupation coinciding with the end of this warming period and the onset of the LIA of ~600-150 BP, and then extending into the historic period. This directly addresses one of the main data gaps in Aleutian prehistory,

which is to develop an understanding of the relationship between the relatively unknown palaeoenvironment and patterns of site occupation (West et al. 2007:51). As a result, this demonstrates the potential of otolith geochemical studies spanning wide time frames. The continued addition of otolith data (both modern and archaeological) and larger datasets will increase the value, relevance, and applicability of new and existing otolith $\delta^{18}O$ data.

### 6.8 Atlantic Cod Discussion

Atlantic cod otoliths were also sampled as a component of this study, mainly to develop a methodological and interpretative approach, but also to assess the efficacy of this sampling strategy for archaeological materials and to add time-depth to existing datasets. A selection of modern Atlantic cod otoliths were analyzed as well as archaeological cod otoliths from the 17$^{th}$ century fishing settlement of Ferryland, Newfoundland. The otoliths have a tight spatial and temporal context, and are associated with the buttery/pantry and kitchen of the Mansion House dated to between 1620 and 1696 (Barry Gaulton personal communication 2015).

In general, the Island of Newfoundland has highly acidic soils impeding the preservation of faunal material; however, the faunal material from Ferryland is relatively well preserved and has been extensively analyzed (e.g. Guiry et al. 2012; Hodgetts 2006; Tourigny 2009). Additionally, the cod fishery at Ferryland is documented and has been well studied (e.g. Betts et al. 2014, Hodgetts 2006, Pope 2004). Here, the focus is primarily on interpreting the isotope results and integrating these with known datasets, as well as to evaluate the methodological approach. Microstructural and isotope results indicate a variable season of occupation, with two Ferryland otoliths indicating cold

season of capture and two indicating warm season of capture, based on the pattern of translucent and opaque banding (Table 5.6).

Atlantic cod $\delta^{18}O_{otolith}$ range from -0.12 to +2.97‰, with modern samples ranging from 0.12 to +2.92‰ and archaeological samples ranging from -0.12 to +2.97‰ (Figures 5.13 and 5.165). In comparison, Gao et al.'s (2001) analysis of reared Norwegian Atlantic cod produced values ranging from -0.21 to 1.98‰, Jamieson's (2001) averaged values range from -0.07(±0.37) to +2.22‰ (±0.26‰), and Høie et al's (2004) values range from ~-0.5 to ~+2.5‰.

The general pattern that has been demonstrated for Atlantic cod $\delta^{18}O_{otolith}$ is similar to that already discussed for Pacific cod. The main identifiable pattern consists of a sub-annual shift around year 1, followed by sub-annual variation up to four years of age, with a subsequent lack of identifiable seasonal variation after four years (Gao et al. 2001). This lifestage pattern is not clearly visible within this assemblage of modern and archaeological Atlantic cod otoliths, partially due to the limited sample size and the lack of consecutive usable values. Otolith Ref-01 most clearly fits this pattern, with Ref-09 and Ref-06 also demonstrating depleted values at hatch with general enrichment throughout the fish's life. However, overall variability is more dominant than a patterned lifestage.

The selection of Ferryland otoliths does not demonstrate low values at hatch. Both otoliths with usable core values are high (1.72, 2.22‰), followed by lower values at the first winter (0.05, 0.92‰). Only one Ferryland otolith (F-13; Figure 5.14) has consecutive usable values spanning the first two years allowing for this comparison. Otolith F-13

demonstrates a high hatch value (2.22‰), followed by a low winter value (0.92‰) and a clear cyclical seasonal pattern up to year 3 (Figure 5.14).

Further sampling is required to discuss the potential relationship between these higher values and the sampling strategy. However, both Ferryland samples with usable core values (F06, F13) display high values, and the same sampling strategy was employed for both modern and archaeological samples. As discussed previously, highly saline and colder hatch environments can cause higher $\delta^{18}O$ values. Although both stable salinity and temperature are integral to cod survival, a colder hatch environment has been demonstrably linked to a poor juvenile survival rate (Rose et al. 2008). Although $\delta^{18}O$ correlates positively with salinity, temperature is considered the primary regulating factor, and salinity has not been demonstrated to overwhelm the seasonal effects of temperature (Elsdon and Gilanders 2002:1806; Weidman and Millner 2000:332). For example, Weidman and Millner (2000) demonstrate that 1 ‰ variation in salinity influences $\delta^{18}O_{otolith}$ by 0.4‰, and they argue that the North Atlantic, in general has seasonal variations that tend to be less than 0.5 ‰, whereas temperature variation ranges between 3 and 8°C, indicating that temperature can be considered the dominant factor influencing identifiable variation.

As previously discussed in relation to Pacific cod, Atlantic cod $\delta^{18}O_{otolith}$ represent bottom temperature within 1°C (Thorrold et al. 1997; Weidman and Millner 2000; Gao et al. 2001). Overall, the range for Ferryland values is 3.09‰ (15.45°C). This range of temperature is beyond the limits of known cod temperature preference. Generally, Atlantic cod demonstrate a preference for temperatures ranging between -0.5°C to 10°C,

but there is variation within this range and they can inhabit waters up to 20°C and as cold as -1.5°C (Jamieson 2001:3; COSEWIC 2003:20).

Off the coast of Newfoundland, cod migrate seasonally from offshore overwintering and spawning grounds to inshore feeding areas along the coast, moving in a circular seasonal migratory route through the trenches of the continental shelf (Jamieson et al. 2004:93-97; Rose 1993). Juveniles inhabit near shore zones, and generally mature cod inhabit the coldest available waters while juveniles remain in the warmest (Jamieson et al. 2004:95; Jones and Campana 2009:1500). As a deep water bottom fish, they move into the shallower banks to spawn, usually from late winter to early spring, and depending on the stock, the spawning period varies, but generally lasts three months (Jones and Campana 2009).

As discussed previously, $\delta^{13}C_{otolith}$ does not act as an environmental proxy, and unlike oxygen is considered to be in disequilibrium with ambient water conditions; instead it is a reflection of physiological processes and ambient water conditions, and is an indicator of diet and metabolism (Jamieson et al. 2004; Weidman and Milner 2000:328). The main control factors of cod $\delta^{13}C_{otolith}$ are: age, temperature, trophic level, and depth (Jamieson et al. 2004:84). Most successfully, cod $\delta^{13}C_{otolith}$ is an indicator of the dietary shift as the fish moves to higher trophic level foods, with the $\delta^{13}C$ maxima indicating the age of cod maturity (Gao et al. 2005; Jamieson et al. 2004; Schwarcz et al. 1998).

As displayed in Figures 5.15 and 6.7, Ferryland cod $\delta^{13}C$ values range from -2.93 to -0.62‰, with a mean of -1.43‰. Initial hatch values range from -3.9 to -1.95‰, followed by continued increase within the first three years, and a subsequent relative

stabilization with a range of 1.35‰ (-1.38 to-0.03‰) for the remainder of the cods' life. The overall pattern visible in the Ferryland cod $\delta^{13}C$ distribution is a low hatch value (mean -2.93‰), followed by continued increase in values over the first three years (mean increase of 2.04‰), moving to more stabilized values after year 3. This is in general agreement with the pattern identified by Jamieson et al. (2004) and Gao et al. (2001), which include low initial values, and a general trend of increasing values throughout the fish's life, with year 3 to year 4 marking a transition to increased stabilization. Similar to Jamieson et al. (2004), there are aberrant values, which can be expressions of individual dietary preference and metabolism.

Approximate age of sex sexual maturity for Atlantic cod is three years to four years, which has been identified as the $\delta^{13}C$ maxima in other studies (e.g. Schwarcz et al. 1998; COSEWIC 2003:vi; Gao et al. 2001:451). Seasonal maxima range for this study ranges from year 4 (F-06) to year 5 (F-03, F-13, F-2). However, as discussed above, there is consistent variation between individual fish $\delta^{13}C$ distributions, including within cod of the same stock and captured at the same location, which has been attributed to individual diet preference and difference in metabolism (Jamieson et al. 2004:94).

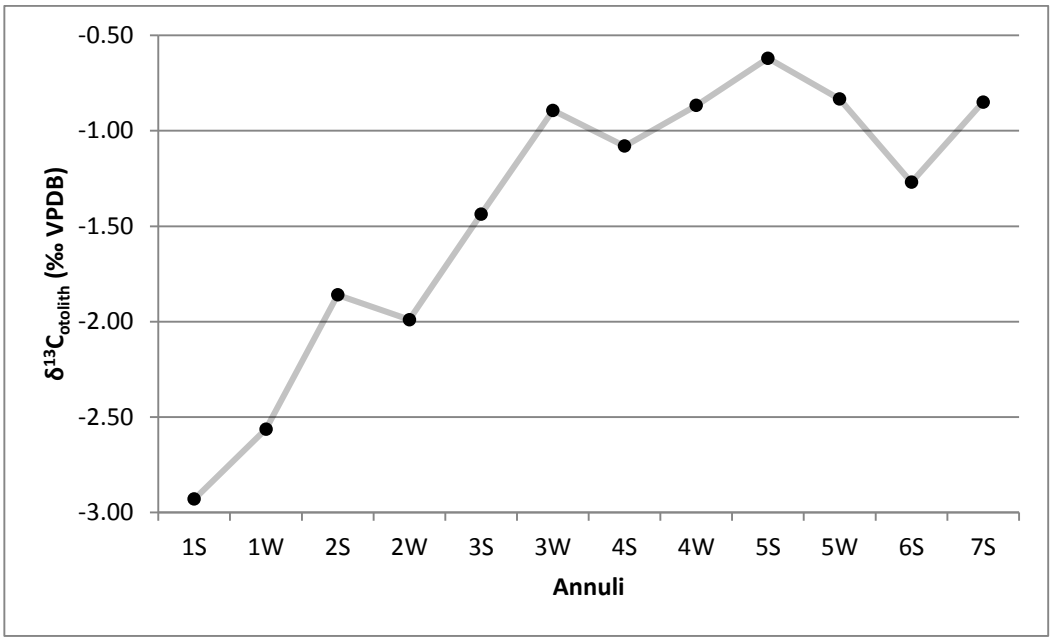



**Figure 6.7: $\delta^{13}C$ values of archaeological Atlantic cod otoliths from Ferryland, NL.**

## Chapter 7: Conclusions

The main objectives of this research are to determine the efficacy of the methodological approach of extracting climatic data from archaeological otoliths; to identify the season(s) *Unangan* harvested Pacific cod at Gertrude Cove, Kiska Island; and to identify the changing climatic conditions over time as inferred from cod ambient water conditions.

This research demonstrates that the high resolution micromilling method, as outlined in Chapter 4, can be used to effectively extract climatic data from archaeological cod otoliths. The study also illustrates the necessity of comparable modern datasets and localized palaeoclimate data to integrate the archaeological $\delta^{18}O_{otolith}$ data. The application of this method in this research differed from existing archaeological studies by identifying and micromilling individual annuli, thus providing a finer temporal resolution. Although micromilling by discrete annuli is a viable approach for extracting climatic data, future work would benefit from a mixed methodological approach that includes higher resolution sampling techniques (e.g. SIMS).

Season of capture is not clearly identifiable through $\delta^{18}O_{otolith}$ values and microstructural analysis. Cycles of seasonal variation become obscured after maturity, as a result $\delta^{18}O$ edge values cannot be used to identify season of capture. Microstructure analysis indicates that two otoliths (K-17, K-20) were harvested during cold water temperatures (translucent bands), and the remaining 5 during warm water temperatures (opaque bands). In contrast, $\delta^{18}O$ edge values indicate that the cod were exposed to the coldest ambient water temperatures closest to the time of capture. Edge values average 0.5‰ higher and 2.4°C lower than average overall values.

Due to Pacific cod's demonstrated preference for stable temperatures, these high $\delta^{18}O$ edge values suggest a behavioural or environmental shift related to capture. It has been argued and supported here that the lack of a cyclical seasonal variation past year 3 indicates that the cod remained within a stable, relatively deep (100-200 m) environment, with spawning and feeding occurring at relatively consistent depths and minimal recorded excursions within the water column. The increase in edge values indicates an increased mobility prior to capture, potentially represented by excursions in the water column previously unprecedented in the mature cod's life. However, the overall trend of an increase in values over time, as opposed to clear seasonal fluctuations, may also indicate that other behavioural, environmental, or sampling methodology factors are influencing the $\delta^{18}O_{otolith}$ values. Future work aligning $\delta^{18}O$ values with annuli at a higher resolution (Helser and Kastelle 2014; Kastelle et al. 2012) will better highlight the relationship between $\delta^{18}O$ values and seasonal banding and allow for increased interpretation of mature cod $\delta^{18}O$ values, and specifically edge values.

Archaeologically, the presence of Pacific cod remains is often used as an indicator of summer occupation in the Aleutians and harvesting is considered to primarily occur during spring and summer when cod reputably move inshore (e.g. Funk 2011; Knecht and Davis 2008; Lefèvre 1997; West et al. 2012). It is demonstrated here that it is more probable that cod were harvested year round. The isotope analysis indicates that the cod were harvested during their exposure to cold water temperatures, and a year round harvest is supported by ethnographic and modern data as well as Pacific cod behavioural patterns. March is the peak spawning season for Pacific cod and modern commercial Pacific cod fisheries predominantly occur during the winter months with highest hook and line

catches in February-March, at depths up to 200 m (Moss 2011:156; Stone 2006:231; Thompson and Dorn 2003:170). Further work refining the season of harvest based on Pacific cod otoliths can contribute to our understanding of the role of seasonality and patterns of procurement in the western Aleutians and contribute to our understanding of seasonal settlement patterns, which is an emerging focus in the western Aleutians (e.g, Funk 2011:48).

Overall, the otoliths demonstrate relatively minimal variation in ambient water conditions over the span of the occupation of Gertrude Cove. For the ~2000 years represented by the otoliths, there is an overall maximum variation of 1.31‰, representing a range of 6.25°C spanning the occupation of Gertrude Cove. The $\delta^{18}O_{otolith}$ values for this Kiska Island assemblage illustrate a variable period at the onset of occupation (1°C variation), followed by a period of stability from maximum ca. 646 to 346 BP, with a subsequent decrease in temperature by about 0.7°C during the final occupation period at Gertrude Cove.

Distinct occupation periods at Gertrude Cove can be directly correlated to identifiable climatic trends, suggesting that changing climatic conditions are essential to understanding the occupational history of Kiska Island. The site was first occupied at the end of the neoglacial cooling period (2704-2455 BP), with evidence of either continuous or reoccupation corresponding with a localized cooling period from 2100 to 1800 BP. During the subsequent warming period from 1100 to 650 BP there is a lack of radiocarbon dates indicating a potential lack of occupation. Evidence for reoccupation coincides with the end of this warming period and the onset of the LIA at ~600-150 BP and extends into the historic period.

In summary, developing a clearer understanding of the significant environmental changes that have occurred in the Aleutian archipelago through time and space is a main research focus of both biological and archaeological research in the region (e.g. Causey et al. 2005; West et al. 2007; Williams et al. 2003). The research presented here demonstrates that through high-resolution stable isotope analysis, temporally specific environmental data can be obtained from archaeological Pacific cod otoliths, and can contribute to our understanding of palaeoclimatic variation over time and seasonal harvesting and occupation patterns within the archaeological record. However, as Burchell et al. (2013b) demonstrate, the extraction of behavioural conclusions from isotopic data requires the extensive collection of modern and archaeological material, and results highlight the intricacies of human behaviour as opposed to providing clear seasonal distinctions.

For Atlantic and Pacific cod, this data demonstrates the potential to add much needed time-depth to existing baseline data for both studies of modern and past populations. With the recent collapse of nearly every major world fishery and the growing discussion of the issues related to modern baseline data, archaeological data is becoming increasingly necessary (Amorosi et al. 1994; Erlandson and Rick 2008). As Corbett et al. (2008:43) point out, the greater our understanding of ecosystem processes the clearer it becomes that historical records alone are not adequate. Archaeological evidence for over 5000 years of interaction between humans and cod in the northern hemisphere illustrates that the application of half a century's worth of fisheries data is insufficient to inform management strategies (Betts et al. 2011:188).

This thesis demonstrates the effectiveness of this methodology for further investigations of archaeological material. However, the amount of species specific data required limits the capacities of this method where extensive modern and archaeological comparable data are not available. As Campana (2005:489) indicates, due to issues interpreting the complicated relationship between temperature and salinity and the effects on otolith microchemistry, environmental reconstructions have not been significantly successful for modern otolith analyses. Due to the inability to further test this relationship or explore the assumptions of oxygen and carbon uptake in archaeological or fossilized otoliths, palaeoenvironmental reconstructions have been substantially more accepted. By acknowledging the assumptions and using the data as a building block to develop a better understanding of past water conditions, fish life histories, and the relationship between these and the occupants of the archaeological site, there is significant value in the geochemical study of archaeological otoliths.

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# APPENDIX A: OTOLITH CATALOGUE

| Cat. ID | N | Site | Unit/E | Level | Quad | Side | Taxon | Date Asso | Lngth (mm) | Wid (mm) | Thick (mm) | Wght (mg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REF-01 | 1 | Ref | | | | R | G. morhua | modern | 13.7 | 6.1 | 2.1 | 210 |
| REF-02 | 1 | Ref | | | | L | G. morhua | modern | 13.9 | 6.2 | 2.1 | 216 |
| REF-03 | 1 | Ref | | | | R | G. morhua | modern | 11.7 | 4.7 | 1.5 | 109 |
| REF-04 | 1 | Ref | | | | L | G. morhua | modern | 11.8 | 4.6 | 1.5 | 110 |
| REF-05 | 1 | Ref | | | | R | G. morhua | modern | 13.1 | 5.6 | 1.9 | 191 |
| REF-06 | 1 | Ref | | | | L | G. morhua | modern | 12.7 | 6.0 | 2.0 | 186 |
| REF-07 | 1 | Ref | | | | L | G. morhua | modern | 14.5 | 6.4 | 2.1 | 271 |
| REF-08 | 1 | Ref | | | | R | G. morhua | modern | 14.4 | 6.2 | 2.2 | 231 |
| REF-09 | 1 | Ref | | | | R | G. morhua | modern | 14.8 | 6.8 | 2.2 | 260 |
| REF-10 | 1 | Ref | | | | L | G. morhua | modern | 14.8 | 6.7 | 2.1 | 266 |
| REF-11 | 1 | Ref | | | | R | G. morhua | modern | 14.8 | 6.2 | 2.2 | 260 |
| REF-12 | 1 | Ref | | | | L | G. morhua | modern | 14.6 | 6.7 | 2.2 | 274 |
| REF-13 | 1 | Ref | | | | R | G. morhua | modern | 12.3 | 5.3 | 1.7 | 135 |
| REF-14 | 1 | Ref | | | | R | G. morhua | modern | 14.5 | 6.7 | 2.3 | 265 |
| REF-15 | 1 | Ref | | | | L | G. morhua | modern | 14.4 | 6.5 | 2.2 | 262 |
| REF-16 | 1 | Ref | | | | R | G. morhua | modern | 14.4 | 6.5 | 2.3 | 266 |
| REF-17 | 1 | Ref | | | | L | G. morhua | modern | 14.3 | 6.5 | 2.2 | 264 |
| REF-18 | 1 | Ref | | | | R | G. morhua | modern | 14.7 | 6.8 | 2.2 | 279 |
| REF-19 | 1 | Ref | | | | L | G. morhua | modern | 21.5 | 10.5 | 3.4 | 839 |
| REF-20 | 1 | Ref | | | | L | G. morhua | modern | 17.7 | 7.9 | 2.8 | 452 |
| REF-21 | 1 | Ref | | | | L | G. morhua | modern | 16.7 | 8.1 | 2.9 | 491 |
| REF-22 | 1 | Ref | | | | R | G. morhua | modern | 20.5 | 9.1 | 3.7 | 871 |
| REF-23 | 1 | Ref | | | | R | G. morhua | modern | 18.7 | 8.8 | 3.2 | 577 |
| FER-01 | 1 | Ferry | E765 | | | R | G. morhua/G. ogac | 1620s | 12.67 | 5.55 | 1.87 | 149 |
| FER-02 | 1 | Ferry | E765 | | | L | G. morhua/G. ogac | 1620s | 16.1 | 7.4 | 2.51 | 369 |
| FER-03 | 1 | Ferry | E765 | | | R | G. morhua/G. ogac | 1620s | 16.02 | 8.17 | 2.84 | 428 |
| FER-04 | 1 | Ferry | E765 | | | R | G. morhua/G. ogac | 1620s | 14.59 | 6.79 | 2.26 | 232 |
| FER-05 | 1 | Ferry | E765 | | | L | G. morhua/G. ogac | 1620s | 12.36 | 6.09 | 1.8 | 161 |
| FER-06 | 1 | Ferry | E765 | | | L | G. morhua/G. ogac | 1620s | 14.08 | 6.01 | 1.95 | 215 |
| FER-07 | 1 | Ferry | E52 | | | L | G. morhua/G. ogac | Undet. | 17.95 | 7.9 | 2.72 | 477 |
| FER-08 | 1 | Ferry | E52 | | | R | G. morhua/G. ogac | Undet. | 14.11 | 6.58 | 2.28 | 257 |
| FER-09 | 1 | Ferry | E634 | | | L | G. morhua | 1620s-169 | 19.16 | 7.66 | 3.52 | 624 |
| FER-10 | 1 | Ferry | E634 | | | R | G. morhua | 1620s-169 | 14.07 | 5.64 | 2 | 204 |
| FER-11 | 1 | Ferry | E634 | | | L | G. morhua | 1620s-169 | 13.68 | 6.49 | 2.15 | 232 |
| FER-12 | 1 | Ferry | E634 | | | R | G. morhua/G. ogac | 1620s-169 | 14.88 | 7.06 | 2.57 | 353 |
| FER-13 | 1 | Ferry | E634 | | | L | G. morhua | 1620s-169 | 16.75 | 8.09 | 2.92 | 454 |
| FER-14 | 1 | Ferry | E627 | | | L | G. morhua/G. ogac | Undet. | 13.69 | 6.77 | 2.29 | 200 |
| FER-15 | 1 | Ferry | E634 | | | L | G. morhua | 1620s-169 | 14.15 | 5.93 | 2.05 | 222 |
| FER-16 | 1 | Ferry | E634 | | | L | G. morhua/G. ogac | 1620s-169 | 10.96* | 6.17 | 1.75 | 139 |
| FER-17 | 1 | Ferry | E634 | | | L | G. morhua | 1620s-169 | 14.8 | 7.15 | 2.62 | 318 |
| FER-18 | 1 | Ferry | E634 | | | R | G. morhua | 1620s-169 | 14.34 | 6.29 | 2.23 | 271 |
| FER-19 | 1 | Ferry | E634 | | | L | G. morhua | 1620s-169 | 9.85* | 7.84 | 3.01 | 394 |
| FER-20 | 1 | Ferry | E634 | | | R | G. morhua | 1620s-169 | 12.45 | 7.3 | 2.61 | 296 |
| FER-21 | 1 | Ferry | E52 | | | L | G. morhua | Undet. | 15.15 | 6.89 | 2.26 | 306 |
| FER-22 | 1 | Ferry | E52 | | | Undet | Undet | Undet. | 19.94 | 10.8 | 3.31 | 630 |
| FER-23 | 1 | Ferry | E52 | | | Undet | Undet | Undet. | | | | 169 |
| FER-24 | 1 | Ferry | E52 | | | R | G. morhua | Undet. | 17.28 | 7.01 | 1.92 | 224 |
| FER-25 | 1 | Ferry | E52 | | | R | G. morhua | Undet. | 14.53 | 6.44 | 2.8 | 252 |
| FER-26 | 1 | Ferry | E52 | | | L | G. morhua | Undet. | 15.34 | 6.98 | 2.73 | 331 |
| FER-27 | 1 | Ferry | E52 | | | R | G. morhua | Undet. | 16.88 | 7.05 | 2.51 | 205 |
| FER-28 | 1 | Ferry | E52 | | | L | G. morhua | Undet. | 12.81* | 5.95 | 1.9 | 106 |
| FER-29 | 1 | Ferry | E52 | | | R | G. morhua | Undet. | 16.87* | 8 | 2.81 | 412 |
| FER-30 | 1 | Ferry | E52 | | | L | G. morhua | Undet. | 12.99* | 6.56 | 2 | 157 |

| Cat. ID | N | Site | Unit/E | Level | Quad | Side | Taxon | Date Asso | Lngth (mm | Wid (mm) | Thick (mm) | Wght (mg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FER-31 | 1 | Ferry | E52 | | | R | G. morhua | Undet. | 14.79* | 8.69 | 3.16 | 431 |
| FER-32 | 1 | Ferry | E634 | | | L | G. morhua/G. ogac | 1620s-169 | 11.41 | 5.23 | 1.66 | 130 |
| FER-33 | 1 | Ferry | E634 | | | Undet | G. morhua/G. ogac | 1620s-169 | 11.96 | 4.86 | 2 | 138 |
| FER-34 | 1 | Ferry | E788 | | | R | G. morhua | 1620s-169 | 13.61 | 6.48 | 2.24 | 257 |
| FER-35 | 1 | Ferry | E788 | | | Undet | G. morhua/G. ogac | 1620s-169 | 13.24 | 6.92 | 2.88 | 325 |
| FER-36 | 1 | Ferry | E788 | | | Undet | G. Morhua | 1620s-169 | 10.96* | 6.58 | 1.56* | 163 |
| KIS-01 | 1 | Gert | 2 | 26 | | R | G. macrocephalus | 2465 ± 15 | 21.63 | 11.42 | 3.89 | 994 |
| KIS-02 | 1 | Gert | 2 | 26 | | L | G. macrocephalus | | 21.47 | 11.47 | 3.88 | |
| KIS-03 | 1 | Gert | 2 | 26 | | R | G. macrocephalus | | 22.77 | 12.57 | 4.2 | |
| KIS-04 | 1 | Gert | 2 | 26 | | L | G. macrocephalus | 2465 ± 15 | 21.88 | 12.84 | 3.97 | 1.074 |
| KIS-05 | 1 | Gert | 2 | 26 | | R? | Gadidae | | 18.56 | 9.71 | 3.04 | |
| KIS-06 | 1 | Gert | 2 | 26 | | R | G. macrocephalus /T. chalcogramma | | 20.69 | 10.41 | 3.2 | |
| KIS-07 | 1 | Gert | 4 | 4 | | L | G. macrocephalus | | 23.38 | 12.65 | 4.65 | 1.266 |
| KIS-08 | 1 | Gert | 4 | 2 | | R | G. macrocephalus | 330 ± 20 | 24.75 | 14.35 | 5.19 | 1.672 |
| KIS-09 | 1 | Gert | 2 | 5 | | R | G. macrocephalus | 330 ± 20 | 19.11 | 10.82 | 3.58 | 826 |
| KIS-10 | 1 | Gert | 2 | 5 | | R | G. macrocephalus | | 20.93 | 12.04 | 4.02 | |
| KIS-11 | 1 | Gert | 2 | 10 | | undet | Undet (halibut?) | | | | | |
| KIS-12 | 1 | Gert | 2 | 10 | | L | G. macrocephalus | 600 ± 15 | 21.78 | 12.11 | 4.09 | 1.32 |
| KIS-13 | 1 | Gert | 2 | 10 | | R | G. macrocephalus | | 22.48 | 12.28 | 4.01 | |
| KIS-14 | 1 | Gert | 2 | 10 | | L | G. macrocephalus /T. chalcogramma | | 20.99 | 10.85 | 3.82 | |
| KIS-15 | 1 | Gert | 2 | 10 | | L? | Gadidae | | 23.99 | 12.53 | 3.93 | |
| KIS-16 | 1 | Gert | 2 | 10 | | L | G. macrocephalus | | 24.87 | 11.97 | 3.78 | |
| KIS-17 | 1 | Gert | 2 | 10 | | L | G. macrocephalus | 600 ± 15 | 20.79 | 12.27 | 3.95 | 1.086 |
| KIS-18 | 1 | Gert | 2 | 10 | | R | Gadidae | | 18.32* | 11.27 | 3.58 | |
| KIS-19 | 1 | Gert | 2 | 13 | | L | G. macrocephalus | | 20.02 | 11.54 | 4.1 | |
| KIS-20 | 1 | Gert | 2 | 13 | | L | G. macrocephalus /T. chalcogramma | 600 ± 15 | 20.46 | 9.86 | 3.67 | 824 |
| KIS-21 | 1 | Gert | 2 | 15 | | L | G. macrocephalus | | 22.95 | 13.08 | 4.12 | |
| KIS-22 | 1 | Gert | 4 | 2 | | undet | Gadidae; Undet | | 21.21 | 10.59 | 3.77 | |
| KIS-23 | 1 | Gert | 2 | 9 | | R | Gadidae | | 19.14 | 9.89 | 3.14 | |
| KIS-24 | 1 | Gert | 2 | 9 | | R | G. macrocephalus | | 23.8 | 13.34 | 3.83 | |
| KIS-25 | 1 | Gert | 2 | 7 | | R | G. macrocephalus | | 19.28 | 11.14 | 3.42 | |
| KIS-26 | 1 | Gert | 2 | 5 | | undet | Gadidae | | 8.26* | 9.68 | 3.33 | |
| KIS-27 | 1 | Gert | 2 | 4 | | L | G. macrocephalus | | 23.18 | 11.99 | 3.82 | |
| KIS-28 | 1 | Gert | 2 | 4 | | R | Gadidae | | 12.26 | 10.48 | 3.08 | |
| KIS-29 | 1 | Gert | 2 | 4 | | undet | Unidentified | | 15.71 | 12.51 | 2.37 | |
| KIS-30 | 1 | Gert | 2 | 4 | | R | T. chalcogramma /M. proximus | | 18.59 | 10.87 | 3.45 | |
| KIS-31 | 1 | Gert | 2 | 4 | | undet | T. chalcogramma /M. proximus | | 17.75* | 11.57 | 3.98 | |
| KIS-32 | 1 | Gert | 2 | 4 | | L | E. gracilis/ M. proximus | | 16.51 | 8.5 | 2.74 | |
| KIS-33 | 1 | Gert | 2 | 4 | | undet | Gadidae | | 9.49* | 11.09* | 2.85 | |
| KIS-34 | 1 | Gert | 2 | 4 | | unid | Undet. (Gadidae?) | | 5.72* | 8.04* | 2.02 | |
| KIS-35 | 1 | Gert | 2 | 4 | | unid | Undet. (Gadidae?) | | 3.9* | 4.72* | 1.7 | |
| KIS-36 | 1 | Gert | 2 | 2 | | R | G. macrocephalus | | 21.89 | 11.76 | 3.71 | |
| KIS-37 | 1 | Gert | 2 | 2 | | R | Gadidae | | 14.3* | 10.07 | 3.68 | |
| KIS-38 | 1 | Gert | 2 | 12 | | L | G. macrocephalus | | 22.87 | 12.14 | 4.17 | |
| KIS-39 | 1 | Gert | 2 | 12 | | L | M. proximus/ G. macrocephalus | | 17.8 | 9.09 | 3.77 | |
| KIS-40 | 1 | Witch | 1 | Surf | | undet | Gadidae | | 12.78* | 7.71* | 2.91 | |
| KIS-41 | 1 | Witch | 1 | 4 | SE | undet | Undet | | 12.84* | 7.34* | 2.97 | |
| KIS-42 | 1 | Witch | 1 | 3 | SW | L | Gadidae | | 14.83* | 8.91 | 3 | |

| Cat. ID | N | Site | Unit/E | Level | Quad | Side | Taxon | Date Asso | Lngth (mm | Wid (mm) | Thick (mm) | Wght (mg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KIS-42 | 1 | Witch | 1 | 3 | SW | L | Gadidae | | 14.83* | 8.91 | 3 | |
| KIS-43 | 1 | Witch | 1 | 4 | SW | R | T. chalcogramma | | 21.56 | 10.31 | 3.68 | |
| KIS-44 | 1 | Witch | 1 | 4 | SW | R | T. chalcogramma | | 20.93 | 9.56 | 3.32 | |
| KIS-45 | 3 | Witch | 1 | 5 | SE | unid | Unidentified | | | | | |
| KIS-46 | 1 | Witch | 1 | Surf | | unid | Undet | | 14.36* | 8.01* | 2.68* | |
| KIS-47 | 1 | Witch | 1 | 6 | NW | unid | Unidentified | | | | | |
| KIS-48 | 1 | Witch | 1 | 5 | NE | undet | Undet | | 12.43* | 11.07 | 3.69* | |
| KIS-49 | 1 | Witch | 1 | 5 | NE | undet | Gadidae | | 12.09* | 9.36 | 3.43 | |
| KIS-50 | 1 | Witch | 1 | 5 | NE | undet | Undet | | 9.87* | 9.2 | 3.14 | |
| KIS-51 | 1 | Witch | 1 | 6 | SE | unid | Unidentified | | 12.75* | 8.03* | 1.95* | |
| KIS-52 | 1 | Witch | 1 | 6 | SE | unid | Unidentified | | | | | |
| KIS-53 | 1 | Witch | N1E2 | 8 | SW | R | Gadidae | | 10.26* | 10.02* | 3.94 | |
| KIS-54 | 2 | Witch | N1E2 | 8 | SW | unid | Unidentified | | | | | |
| KIS-55 | 1 | Witch | N0E2 | 4 | NE | unid | Unidentified | | | | | |
| KIS-56 | 1 | Witch | N0E2 | 1 | SE | R | G. macrocephalus | | 19.76 | 1301 | 4.27 | |
| KIS-57 | 1 | Witch | N0E2 | 1 | SW | undet | Gadidae | | 12.41* | 8.35 | 2.7 | |
| KIS-58 | 1 | Witch | N1E2 | 7 | SW | undet | G. macrocephalus | | 17.25* | 12.39 | 4.34 | |
| KIS-59 | 1 | Witch | N1E2 | 8 | SE | L | Gadidae | | 9.55* | 9.6 | 2.99 | |
| KIS-60 | 1 | Witch | N1E1 | 7 | NW | L | Gadidae | | 14.27* | 11.13 | 3.59 | |
| KIS-61 | 1 | Witch | N2E1 | 5 | SE | unid | Gadidae? | | | | | |
| KIS-62 | 1 | Witch | N1E1 | 6 | SE | unid | Undet | | | | | |
| KIS-63 | 1 | Witch | N1E1 | 9 | SE | R | G. macrocephalus | | 20.01 | 12.39 | 4.3 | |
| KIS-64 | 1 | Witch | N1E1 | 6 | NE | unid | Undet | | | | | |
| KIS-65 | 1 | Witch | N1E2 | 7 | SE | unid | Undet | | 13.99* | 8.99 | 2.83 | |
| KIS-66 | 1 | Witch | N2E2 | 7 | NW | unid | Gadidae | | 18.51* | 8.56* | 2.90* | |
| KIS-67 | 1 | Witch | N2E2 | 6 | SW | L? | G. macrocephalus | | 18.52* | 13.21* | 3.76 | |
| KIS-68 | 2 | Witch | N1E1 | 6 | SW | unid | Undet | | | | | |
| KIS-69 | 1 | Witch | N1E2 | 5 | NE | unid | Undet; Gadidae? | | 9.93* | 10.93* | 3.4 | |
| KIS-70 | 1 | Witch | N1E1 | 7 | SE | unid | Undet | | 11.91* | 9.61* | 3.11* | |
| KIS-71 | 1 | Witch | N1E2 | 4 | SE | unid | Gadidae | | 12.3* | 7.6* | 3.46 | |
| KIS-72 | 1 | Witch | N0E0 | 8 | NW | unid | Undet | | 12.63* | 9.1* | 3.35* | |
| KIS-73 | 1 | Witch | N1E2 | 7 | NW | undet | Gadidae | | 16.54* | 9.92* | 3.16 | |
| KIS-74 | 1 | Witch | N1E2 | 7 | SE | R | G. macrocephalus | | 21.84* | 12.21 | 4.06 | |
| KIS-75 | 1 | Witch | N1E2 | 8 | NE | undet | Gadidae | | 17.87* | 9.04* | 3.7 | |
| KIS-76 | 1 | Witch | N1E2 | 9 | NE | undet | Gadidae | | 15.65* | 10.09 | 3.31 | |
| KIS-77 | 1 | Witch | N1E2 | 8 | NW | undet | Undet | | 13.83* | 9.82* | 2.67* | |
| KIS-78 | 1 | Witch | N0E0 | 3 | SW | unid | Unidentified | | | | | |
| KIS-79 | 1 | Witch | N0E0 | 3 | SW | unid | Undet | | 10.56* | 9.9* | 2.31* | |
| KIS-80 | 1 | Witch | N0E0 | 3 | SW | unid | Undet; Gadidae? | | 17.70* | 10.8* | 4.2 | |
| KIS-81 | 8 | Witch | Unit 1 | 6 | SW | unid | Unidentified | | | | | |
| KIS-82 | 1 | Witch | Unit 1 | 6 | SW | undet | Undet; Gadidae? | | 10.46* | 10.55* | 3.66 | |
| KIS-83 | 1 | Witch | N1E2 | 8 | NE | undet | Undet | | 11.97 | 10.44 | 4.69 | |
| KIS-84 | 1 | Witch | N1E2 | 8 | NE | undet | Undet | | 18.58* | 14.79* | 5.17 | |
| KIS-85 | 1 | Witch | N1E2 | 8 | NE | L | G. macrocephalus | | 17.48* | 10.8 | 3.8 | |
| KIS-86 | 1 | Witch | N1E2 | 8 | NE | R | G. macrocephalus | | 22.23 | 11.55 | 3.5 | |
| KIS-87 | 4 | Witch | N1E2 | 8 | NE | undet | Undet | | | | | |
| KIS-88 | 4 | Witch | N1E2 | 8 | NE | undet | Gadidae | | 16.19* | 10.25* | 3.9 | |
| KIS-89 | 4 | Witch | N1E2 | 8 | NE | undet | Gadidae | | 16.23* | 9.56* | 3.3 | |
| KIS-90 | 4 | Witch | N1E2 | 8 | NE | undet | Gadidae | | 17.96* | 929* | 3.33* | |
| KIS-91 | 4 | Witch | N1E2 | 8 | NE | R | Gadidae | | 18.27* | 10.72* | 3.67 | |
| KIS-92 | 4 | Witch | N1E2 | 8 | NE | R | M. proximus/ T. chalcogramma | | 24.14 | 11.14 | 4.08 | |
| KIS-93 | 4 | Witch | N1E2 | 8 | NE | R | G. macrocephalus | | 26.71 | 14.33 | 4.72 | |
| KIS-94 | 8 | Witch | N2E2 | 8 | SW | R | M. proximus/ T. chalcogramma | | 16.56 | 10.92 | 3.09 | |

| Cat. ID | N | Site | Unit/E | Level | Quad | Side | Taxon | Date Asso | Lngth (mm | Wid (mm) | Thick (mm) | Wght (mg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KIS-95 | 1 | Witch | N1E1 | 4 | SE | L | Gadidae | | 17.87 | 11.57 | 3.64 | |
| KIS-96 | 1 | Witch | N1E2 | 8 | SW | undet | Gadidae | | 7.52* | 15.81 | 3.37 | |
| KIS-97 | 1 | Witch | N1E2 | 8 | SW | undet | Gadidae | | 16.75 | 9.31 | 3.1 | |
| KIS-98 | 1 | Witch | N0E2 | 5 | NE | undet | Gadidae | | 11.06 | 10.98 | 3.4 | |
| KIS-99 | 1 | Witch | N0E0 | 1 | undet | undet | Undet | | 12.02 | 9.34 | 2.78 | |
| KIS-100 | 1 | Witch | N0E0 | 4 | NE | undet | Undet | | 17.62 | 12.63 | 4.16 | |

## APPENDIX B: STABLE ISOTOPE ($\delta^{18}O$, $\delta^{13}C$) LAB RESULTS

| PACIFIC COD | | | | |
|---|---|---|---|---|
| **Date Analyzed** | **Sample ID** | **Weight (µg)** | **δ13C (‰ VPDB)** | **δ18O (‰ VPDB)** |
| 05/06/2013 | KIS-01 1S core | 49.1ug | -1.14 | 1.89 |
| | KIS-01 1.5 | 46.3ug | -0.64 | 2.08 |
| | KIS-01 1W | 41.5ug | -0.57 | 2.51 |
| | KIS-01 2S | 40.4ug | -1.60 | 2.34 |
| | KIS-01 2W | 52.6ug | -1.16 | 2.11 |
| | KIS-01 3S | 48.6ug | -0.66 | 2.41 |
| | KIS-01 3W | 51.4ug | -0.62 | 2.60 |
| | KIS-01 4S | 48.2ug | -1.50 | 2.27 |
| | KIS-01 4W | 43.5ug | -1.13 | 2.35 |
| | KIS-01 5S | 45.5ug | -0.98 | 2.38 |
| | KIS-01 5W | 50.2ug | -1.19 | 2.37 |
| | KIS-01 6S | 41.1ug | -0.87 | 2.47 |
| | KIS-01 6W | 47.5ug | -0.93 | 2.53 |
| | KIS-01 7S | 43.6ug | -0.74 | 2.55 |
| | KIS-01 7W | 42.0ug | -0.67 | 2.58 |
| | KIS-01 8S | 42.3ug | -0.55 | 2.67 |
| | KIS-01 8W | 53.6ug | -0.65 | 2.61 |
| | KIS-01 9S | 32.8ug | -0.55 | 2.62 |
| | KIS-01 9W | 46.2ug | -0.45 | 2.67 |
| | KIS-01 EDGE | 42.0ug | -1.30 | 2.73 |
| | KIS-01 12S | 13.4ug | -1.03 | 2.56 |
| | KIS-01 11W | 20.2ug | -0.92 | 2.33 |
| | KIS-01 11S | 16.3ug | -1.61 | 2.33 |
| | KIS-01 10W | 28.5ug | -0.57 | 2.59 |
| | KIS-01 Core rpt | 1 52.9ug | -1.09 | 1.92 |
| | KIS-01 Core rpt2 | 2 51.1ug | -1.11 | 1.87 |
| | KIS-01 1.5 rpt | 42.8ug | -0.71 | 2.06 |
| | KIS-01 1W rpt | 44.3ug | -0.47 | 2.53 |
| | KIS-01 2S rpt | 46.7ug | -1.63 | 2.29 |
| | KIS-01 2W rpt | 43.5ug | -1.15 | 2.04 |
| | KIS-01 8S rpt | 45.5ug | -0.58 | 2.59 |
| | KIS-01 8W rpt | 48.1ug | -0.61 | 2.61 |
| | KIS-1 1.5 rpt2 | 38.9ug | -0.67 | 2.11 |
| 31/07/2013 | KIS-17 Edge | 46ug | -1.06 | 3.01 |
| | KIS-20 1W | 45ug | ~~-1.10~~ | ~~2.14~~ |

| Date Analyzed | Sample ID | Weight (µg) | δ13C (‰ VPDB) | δ18O (‰ VPDB) |
|---|---|---|---|---|
| | KIS-20 2S | 40ug | ~~-1.44~~ | ~~1.84~~ |
| | KIS-20 2W | 48ug | -0.41 | 2.35 |
| | KIS-20 3S | 50ug | -0.80 | 2.41 |
| | KIS-20 3W | 46ug | -0.44 | 2.45 |
| | KIS-20 4S | 45ug | -0.59 | 2.27 |
| | KIS-20 4W | 44ug | -0.38 | 2.33 |
| | KIS-20 5S | 49ug | -0.80 | 2.33 |
| 01/08/2013 | KIS-20 5W | 50ug | -0.75 | 2.24 |
| | KIS-20 6S | 49ug | -0.86 | 2.09 |
| | KIS-20 6W | 49ug | -0.82 | 2.30 |
| | KIS-20 7S | 37ug | -0.90 | 2.31 |
| | KIS-20 7W | 48ug | -0.95 | 2.21 |
| | KIS-20 8S | 50ug | -0.91 | 2.23 |
| | KIS-20 8W | 43ug | -0.93 | 2.29 |
| | KIS-20 Edge | 31ug | -0.10 | 3.19 |
| | KIS-20 Edge | 48ug | 0.16 | 2.91 |
| | KIS-171S core | 40ug | -2.00 | 2.22 |
| | KIS-17 1W | 46ug | -1.23 | 2.29 |
| | KIS-17 2S | 45ug | -1.77 | 2.07 |
| | KIS-17 2W | 51ug | -0.75 | 2.14 |
| | KIS-17 3S | 50ug | -0.98 | 2.07 |
| | KIS-17 3W | 49ug | -1.38 | 1.98 |
| | KIS-17 4S | 44ug | -1.02 | 1.98 |
| | KIS-17 4W | 29ug | -1.02 | 2.12 |
| | KIS-17 5S | 37ug | -1.17 | 2.02 |
| | KIS-17 5W | 38ug | -1.13 | 2.16 |
| | KIS-17 6S | 26ug | -1.35 | 2.23 |
| | KIS-17 6W | 50ug | -1.20 | 2.43 |
| | KIS-17 7S | 45ug | -1.25 | 2.35 |
| | KIS-17 7W | 41ug | -1.04 | 2.43 |
| | KIS-17 8S | 21ug | -0.88 | 2.48 |
| | KIS-17 8W | 47ug | -1.02 | 2.27 |
| | KIS-17 9S | 48ug | -0.87 | 2.52 |
| | KIS-17 9W edge | 46ug | -1.02 | 2.75 |
| 03/08/2013 | KIS-02 1S core | 45ug | -2.51 | 1.96 |
| | KIS-02 1W | 46ug | -0.54 | 2.53 |
| | KIS-02 2S | 50ug | -1.74 | 2.04 |
| | KIS-02 2W | 45ug | -0.13 | 2.27 |

| Date Analyzed | Sample ID | Weight (µg) | δ13C (‰ VPDB) | δ18O (‰ VPDB) |
|---|---|---|---|---|
| | KIS-02 3S | 49ug | -0.17 | 2.12 |
| | KIS-02 3W | 48ug | -0.03 | 2.22 |
| | KIS-02 4S | 47ug | -0.69 | 2.08 |
| | KIS-02 4W | 46ug | -1.63 | 2.18 |
| | KIS-02 5S | 46ug | -2.47 | 2.44 |
| | KIS-02 5W | 50ug | -2.21 | 2.30 |
| | KIS-02 6S | 22ug | -2.08 | 2.21 |
| | KIS-02 6W | 17ug | -2.07 | 2.11 |
| | KIS-02 7S | 10ug | ~~-6.21~~ | ~~-5.86~~ |
| | KIS-02 7W edge | 37ug | ~~-2.67~~ | ~~1.02~~ |
| | KIS-02 Edge | 24ug | ~~-2.20~~ | ~~1.14~~ |
| | KIS-08 1S core | 42ug | -2.27 | 2.30 |
| | KIS-08 1W | 43ug | -0.92 | 2.52 |
| | KIS-08 2S | 48ug | -1.23 | 2.20 |
| | KIS-08 2W | 46ug | -0.78 | 2.41 |
| | KIS-08 3S | 49ug | -0.80 | 2.22 |
| | KIS-08 3W | 51ug | -0.84 | 2.25 |
| | KIS-08 4S | 49ug | -1.29 | 2.39 |
| | KIS-08 4W | 47ug | -1.45 | 2.28 |
| | KIS-08 5S | 34ug | -1.51 | 2.33 |
| | KIS-08 5W | 39ug | -1.60 | 2.32 |
| | KIS-08 6S | 46ug | -1.82 | 2.25 |
| | KIS-08 6W | 47ug | -2.00 | 2.25 |
| | KIS-08 7S | 46ug | -2.12 | 2.34 |
| | KIS-08 7W | 47ug | -2.07 | 2.33 |
| | KIS-08 8S | 46ug | -2.23 | 2.42 |
| | KIS-08 8W | 24ug | -2.16 | 2.53 |
| | KIS-08 9S | 46ug | -2.37 | 2.48 |
| | KIS-08 9W | 36ug | -2.27 | 2.59 |
| | KIS-08 10S | 25ug | -2.36 | 2.55 |
| | KIS-08 edge | 24ug | -2.54 | 2.89 |
| | KIS-08 edge 2 | 50ug | -2.54 | 2.95 |
| 08/10/2013 | KIS-12 1W | 42ug | -1.68 | 2.70 |
| | KIS-12 2S | 48ug | -2.16 | 2.19 |
| | KIS-12 2W | 45ug | -1.42 | 2.29 |
| | KIS-12 3S | 40ug | -0.97 | 2.24 |
| | KIS-12 3W | 48ug | -1.12 | 2.41 |
| | KIS-12 4S | 41ug | -1.39 | 1.98 |
| | KIS-12 4W | 43ug | -1.29 | 2.16 |

| Date Analyzed | Sample ID | Weight (µg) | δ13C (‰ VPDB) | δ18O (‰ VPDB) |
|---|---|---|---|---|
| | KIS-12 5S | 49ug | -1.06 | 2.25 |
| | KIS-12 5W | 48ug | -0.80 | 2.16 |
| | KIS-12 6S | 51ug | -1.37 | 2.17 |
| | KIS-12 6W | 49ug | -1.68 | 2.25 |
| | KIS-12 6W rpt | 57ug | -1.70 | 2.19 |
| | KIS-12 7S | 31ug | -1.70 | 2.51 |
| | KIS-12 7W | 57ug | -1.70 | 2.31 |
| | KIS-12 8S | 55ug | -1.23 | 2.47 |
| | KIS-12 8W | 56ug | -1.97 | 2.40 |
| | KIS-12 8W-9S | 56ug | -1.99 | 2.60 |
| | KIS-12 Edge | 53ug | -1.77 | 2.66 |
| | KIS-12 1S core | 46ug | -2.49 | 1.70 |
| | KIS-09 1W | 51ug | -0.96 | 2.32 |
| | KIS-09 2S | 56ug | -1.95 | 2.41 |
| | KIS-09 2W | 50ug | -0.51 | 2.26 |
| | KIS-09 3S | 54ug | -1.27 | 2.23 |
| | KIS-09 3W | 52ug | -0.69 | 2.14 |
| | KIS-09 4S | 53ug | -0.83 | 2.14 |
| | KIS-09 4W | 55ug | -0.64 | 2.01 |
| | KIS-09 5S | 53ug | -0.91 | 2.24 |
| | KIS-09 6S | 49ug | -0.77 | 2.36 |
| | KIS-09 6W | 22ug | ~~-0.92~~ | ~~1.95~~ |
| | KIS-09 7S | 56ug | -0.60 | 2.39 |
| | KIS-09 edge | 53ug | -0.49 | 2.45 |
| **ATLANTIC COD** | | | | |
| **Date Analyzed** | **Sample ID** | **Weight (µg)** | **δ13C (‰ VPDB)** | **δ18O (‰ VPDB)** |
| 10/30/2012 | REF-01 1S | | -4.22 | 0.34 |
| | REF-01 1W | | -3.24 | 0.12 |
| | REF-01 2S | | -2.85 | 0.64 |
| | REF-01 2W | | -2.10 | 1.87 |
| | REF-01 3S | | -1.66 | 2.56 |
| | REF-01 3W | | -1.49 | 2.32 |
| | REF-01 4S | | -1.26 | 2.73 |
| | REF-01 4W | | -1.24 | 2.33 |
| | REF-01 5S | | -0.89 | 2.68 |
| | REF-06 1S | | -4.48 | 0.20 |
| | REF-06 2S | | -2.09 | 1.24 |
| | REF-06 2W | | -1.59 | 1.18 |
| | REF-06 3S | | -1.43 | 2.33 |

| Date Analyzed | Sample ID | Weight (µg) | δ13C (‰ VPDB) | δ18O (‰ VPDB) |
|---|---|---|---|---|
| | REF-06 4W | | -1.50 | 2.53 |
| | REF-07 1S | | -3.60 | 1.64 |
| | REF-07 1W | | -1.66 | 2.05 |
| | REF-07 2S | | -1.50 | 2.28 |
| | REF-07 2W | | -1.00 | 2.21 |
| | REF-07 3S | | -0.38 | 2.46 |
| | REF-07 3W | | -0.86 | 2.10 |
| | REF-07 4S | | -0.91 | 2.03 |
| | REF-07 4W | | -1.10 | 2.37 |
| | REF-07 5S | | -0.75 | 2.25 |
| | REF-07 5W | | -0.58 | 2.74 |
| | REF-09 1S | | -3.22 | 0.61 |
| | REF-09 1W | | -2.06 | 1.28 |
| | REF-09 2S | | -1.80 | 2.12 |
| 10/31/2012 | REF-09 3S | | -1.59 | 1.78 |
| | REF-09 3W | | -1.37 | 2.33 |
| | REF-09 4S | | -1.41 | 2.06 |
| | REF-09 4W | | -1.62 | 2.20 |
| | REF-09 5S | | -0.88 | 2.92 |
| | REF-09 5W | | -1.65 | 1.88 |
| | REF-09 6S | | -1.22 | 2.10 |
| 09/13/2013 | FER-06-4S | | -1.12 | 0.63 |
| | FER-06-4W | | -0.03 | 2.87 |
| | FER-02-2S | | -2.10 | 2.10 |
| | FER-02-2W | | -1.55 | 1.49 |
| | FER-02-3S | | -1.06 | 1.50 |
| | FER-06-5S | | -0.06 | 2.60 |
| | FER-02-4S | | -0.96 | 2.71 |
| | FER-02-4W | | -1.04 | 1.95 |
| | FER-02-5S | | -0.96 | 1.86 |
| | FER-02-5W | | -0.80 | 1.34 |
| | FER-02-6S | | -1.16 | 2.19 |
| | FER-21-1W | | -3.18 | 1.19 |
| | FER-21-2W | | -3.00 | -0.12 |
| | FER-21-3S | | -2.81 | -0.01 |
| | FER-21-3W | | -1.37 | 1.15 |
| | FER-21-4S | | -2.54 | 0.39 |
| | FER-21-4W | | -1.29 | 1.19 |
| | FER-21-5S | | -1.03 | 1.52 |

| Date Analyzed | Sample ID | Weight (µg) | δ13C (‰ VPDB) | δ18O (‰ VPDB) |
|---|---|---|---|---|
| | FER-21-5W | | -0.81 | 1.80 |
| | FER-21-6W | | -1.53 | 1.33 |
| | FER-21-7S | | -0.82 | 1.80 |
| | FER-13-1S | | -1.95 | 2.22 |
| | FER-13-1W | | -2.29 | 0.92 |
| | FER-13-2S | | -1.62 | 2.65 |
| | FER-13-2W | | -1.42 | 1.56 |
| 09/14/2013 | FER-13-3S | | -0.92 | 2.97 |
| | FER-13-3W | | -1.20 | 2.37 |
| | FER-13-4S | | -1.20 | 2.13 |
| | FER-13-4W | | -1.11 | 2.23 |
| | FER-13-5S | | -0.43 | 2.41 |
| | FER-13-5W | | -0.89 | 2.64 |
| | FER-13-6S | | -1.38 | 2.33 |
| | FER-13-6W | | -1.08 | 2.73 |
| | FER-13-7S | | -0.88 | 2.64 |
| | FER-06-1S | | -3.91 | 1.72 |
| | FER-06-1W | | -2.22 | 0.05 |
| | FER-06-3S | | -0.96 | 2.23 |